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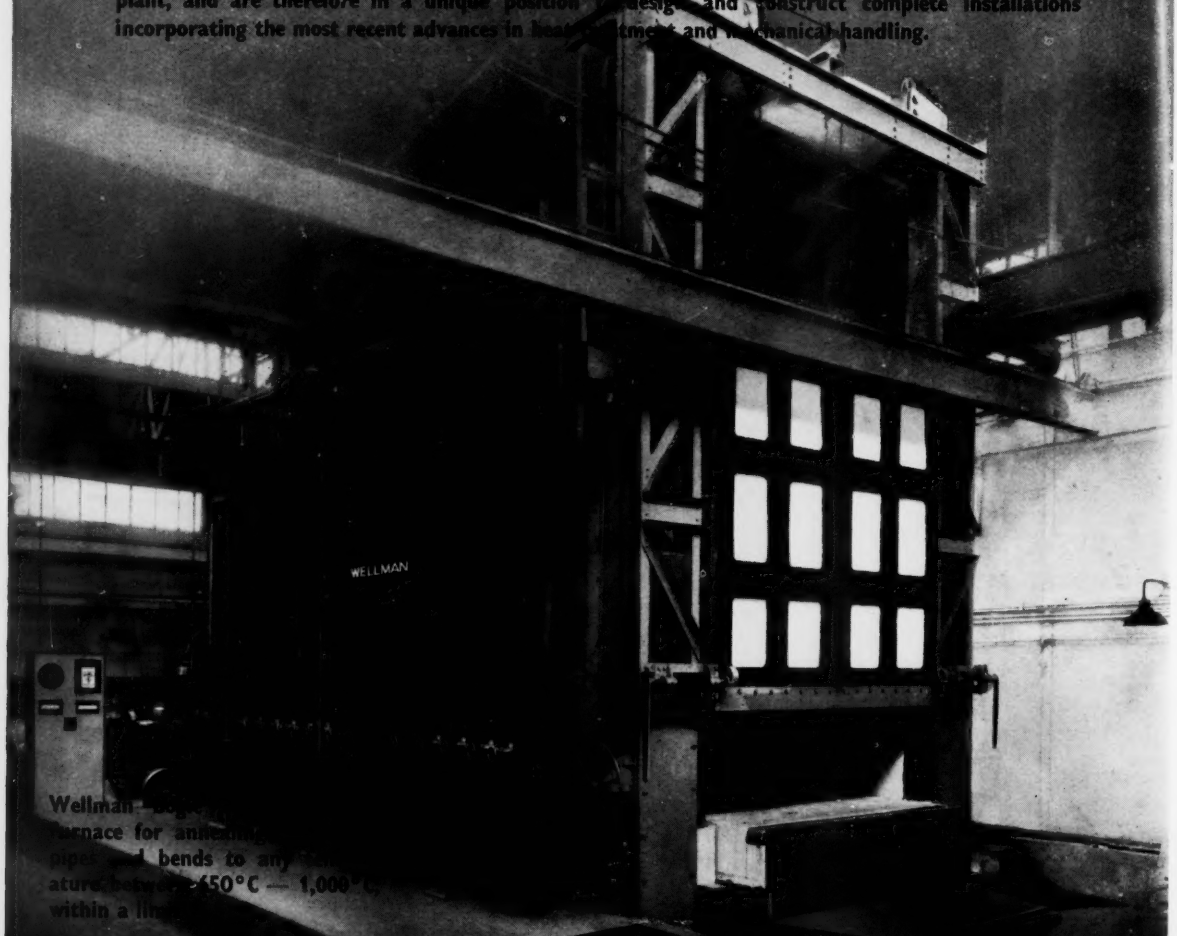

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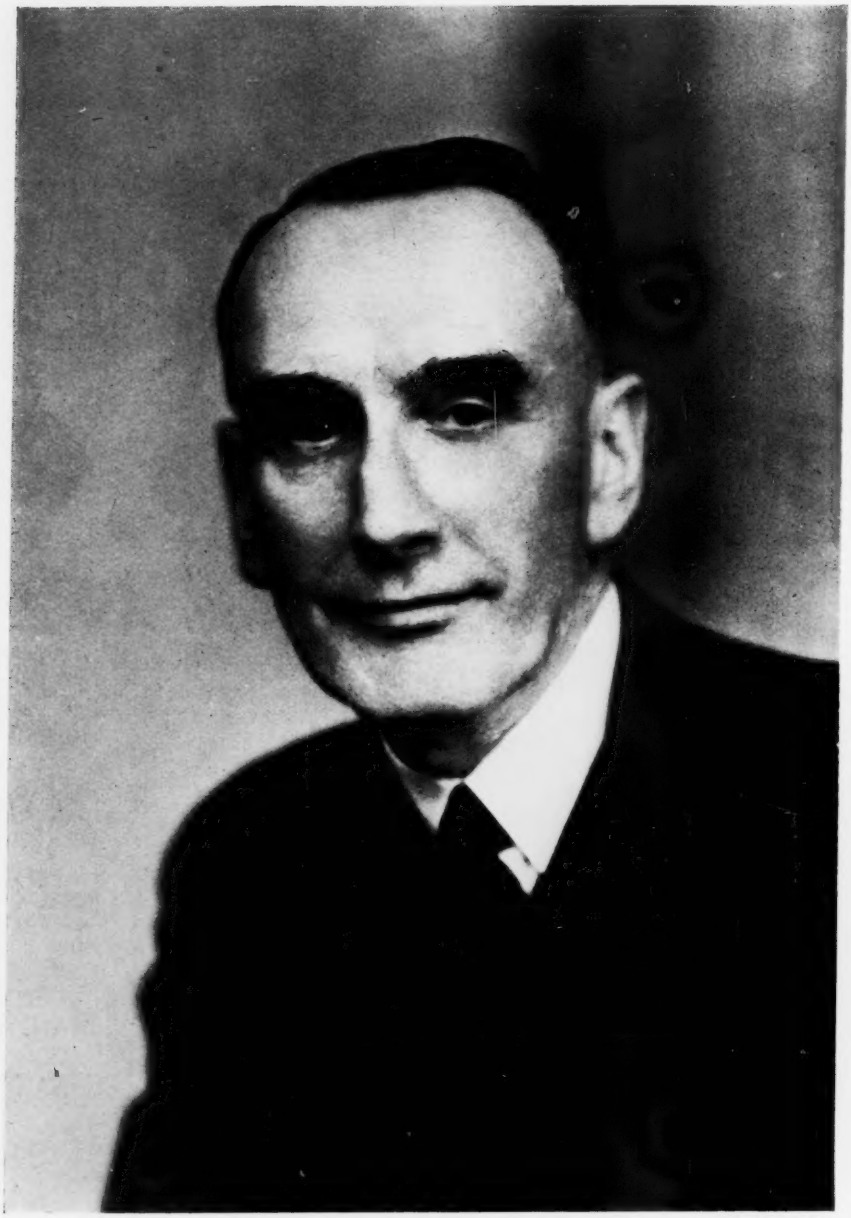
JAMES MITCHELL, C.B.E.

JAMES MITCHELL was born at Oban, Argyll. He received his technical education at the Royal Technical College, Glasgow, and from the staff of the Metallurgical Department he joined Messrs. Stewarts and Lloyds Limited in 1908. He was at first engaged on research work at their Clydesdale Iron and Steel Works and was later appointed Chief Chemist and Metallurgist. His responsibilities were then broadened to cover special research for other of the Company's works and, when the Central Research Department was set up, he became its first Head.

Appointed a Local Director of Messrs. Stewarts and Lloyds Limited in 1932, Mr. Mitchell was Director of Research and in charge of the Bilston Iron and Steel Works of that Company. In 1939 he became Local Director in charge of Iron and Steel Works. His success in this sphere of operations led to his election to the Board in 1947 and to his present appointment as Managing Director of Iron and Steel Production. Although his activities as technical executive and administrator have absorbed much of his time in recent years, Mr. Mitchell has always retained an active interest in research. On the formation of the British Iron and Steel Research Association in 1945, he became Chairman of the Steelmaking Panel, acting in that capacity until 1949, since when he has been a Vice-President of the Association. He is the author of a number of papers concerned principally with Bessemer and rimming steels. The national importance of Mr. Mitchell's work in the iron and steel industry was recognized when, in 1949, he was awarded the C.B.E.

Mr. Mitchell became a Member of The Iron and Steel Institute in 1918, was elected a Member of Council in 1944, Vice-President in 1946, and Honorary Treasurer in 1949. He was awarded the Bessemer Gold Medal in 1950 for contributions to technical development in the iron and steel industry. At the Autumn General Meeting of the Institute held in 1952 he was nominated by the Council to become President for the year 1953-54, and he took office at the Annual General Meeting held last month. Mr. Mitchell is also a Founder Fellow of the Institution of Metallurgists.



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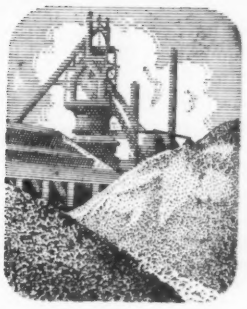
President, 1953-1954



Presidential Address

From the Ore to the Ingot

By James Mitchell, C.B.E.

I must begin by expressing the hope that you will accept my assurance that there is nothing formal in the very sincere thanks which I offer to you now for the honour you have done me in making me your President.

Reflecting on the experiences of the better part of a lifetime in the iron and steel industry, one, not unnaturally, feels an urge to write a 'Then and Now' type of Address. The changes and experiences of the years are, both for the individual and the industry, a story of opportunities taken, chances missed, apparently good ideas gone wrong and apparently bad ones that finally came off: interesting maybe, educative perhaps, but dissatisfying certainly. It is not what has been done that should interest us but what may yet be done. This, I believe, is in line with the real purpose of this Institute, and it is for this reason that I wish to speak of forward-looking rather than backward-looking things, taking as a general theme 'From the Ore to the Ingot'.

In almost one hundred years of ferrous metallurgy there has been no revolutionary change in the cycle of operations by which iron ore is converted to the finished steel ingot, although many abortive attempts have been made. Is our industry immune from the prevailing urge for revolution, or are the shortcomings of the existing system not serious enough to demand it? I am not advocating change for the sake of change, nor yet am I suggesting, in using the word revolution, that there should be one of those cataclysms such as we all associate with political upheavals, those instantaneous explosions which sweep away existing orders without necessarily putting anything better in their place. My purpose is, rather, to re-examine the basic cycle of operations that underlie the efforts of our industry; to satisfy ourselves, if need be, that we are applying to the best advantage an ever-widening scientific knowledge.

I trust you will not consider that I am belittling the results of years of metallurgical endeavour when I point out what a large part of the progress of the industry derives from the work of the electrical and mechanical engineers. The hand-propelled and hand-filled barrow at the blast-furnace has been replaced by the mechanically filled and electrically operated skip. The asthmatic-sounding beam blowing engine has given place to the modern turboblower, and will no doubt in due time be replaced by the still more modern gas turbine, whilst the hot-metal ladle and the pig-casting machine have replaced the husky but excessive labour force of the pig bed. It is these changes—the ability to handle quickly in terms of greater and greater quantities of material—which have made possible the blast-furnace producing 1000 tons or more per day.

At the steel-melting shop the same thing is true. The charging machine and the hot-metal ladle have allowed quicker handling and increased furnace size, giving larger outputs and better control conditions in the furnace. The size of the converters and the better methods of providing blast for them has increased with the growth of mechanical and electrical knowledge.

The furnace designer and the refractory maker have both contributed to increased thermal efficiency and greater outputs. The instrument maker at the blast-furnace and the steel furnace has displaced empirical visual skills, giving precise measurement of quantities, pressures, and temperatures.

This, of course, is not an attack on the metallurgist nor a suggestion that in this sweeping progressive tide of mechanical development he has remained inert and indifferent to the changes going on around him. The record is quite otherwise, especially so far as the development of new materials with improved ranges of properties is concerned. The engineer has had but to ask and it has been given to him, be it a metal to resist high temperature or one of high strength-to-weight ratio to reduce the dimensions of some cumbersome structure. The knowledge of the fundamental

This Address was presented at the Eighty-Fourth Annual General Meeting of the Institute on 30th April, 1953, with the retiring President, Captain H. Leighton Davies, in the Chair.

Mr. Mitchell is Managing Director of Iron and Steel Production of Stewarts and Lloyds, Ltd.

reactions of the production cycle, too, has had continuous attention, resulting in the improvement of the control of operations and quality of product. What I do suggest is that the complete metallurgical cycle from ore to ingot requires review and, possibly, more attention than it appears to be receiving. Most certainly the mechanics of our operations have been altered out of all recognition, yet the basic metallurgical practices have remained the same, and it is in this sphere of our activities that we should be on the alert to the possibilities of beneficial change, even if it be revolutionary.

Let us begin with energy requirements and take a text-book example. If one started with pure oxide of iron, achieved a reduction by carbon monoxide and then melted the metallic product to give pure iron, the actual heat energy required would be about 8½ million B.Th.U. per ton of iron, exclusive of process losses. This figure could be reduced by 1·3 million B.Th.U., if the reduced iron could be put into usable form without melting. It is an intriguing exercise to consider what changes in ferrous metallurgy would follow the discovery of a method to put ferrous metals into service without first melting the iron base. This idea is worthy of serious consideration. The figures I have just quoted show that about 15% of the theoretical heat required to obtain pure iron from pure oxide is used to provide it in the molten state. The quantity of heat actually used in practice to do this is much larger, owing to the radiation and other losses, quite apart from the practical difficulties in furnace construction and maintenance which arise from the use of relatively high temperatures. It is appreciated, of course, that the total heat input would not necessarily be entirely recovered, for in any case the reduction of the oxides requires the use of temperatures of the order of 600–800° C. Bearing in mind, however, that of the total heat content of a ton of molten iron, about 22% represents latent heat of fusion, it will be agreed that there is a strong case, on thermal grounds, for avoiding a change of physical state, if at all possible. Many of you will be aware of the Canadian work on the production of ferrous articles at relatively low temperatures, and this is, of course, a step in the right direction, but it is to be feared that a recognition of the desirability of some such practice is as far as we can hope to go, in the present state of our techniques, except perhaps for limited special applications.

All we can do here, however, is to accept the theoretical minimum heat energy in a ton of molten pure iron as being 8½ million B.Th.U., and to compare this with the energy required in production by present methods. Under the most favourable conditions, about 15 million B.Th.U. are required in the blast-furnace, with a further 3–5 million B.Th.U. in the steelworks or refining process; say, in all, 20 million B.Th.U., or about 2½ times the theoretical figure. It will be appreciated that these heat requirements are for the metallurgical process only and do not include such complementary operations as the conversion of coal to coke and the handling of materials. Even a cursory glance at these figures should do something to shake the complacency with which most of us are wont to regard the well-established blast-furnace and steelmaking sequence of operations.

Although I am not primarily discussing economics, it is perhaps worth noting that, if the value of heat units is assumed to be 6*d.*/therm, the difference between the theoretical ideal and the very best of practical applications is 57*s.* 6*d.*/ton for process heat alone.

It may be thought that this comparison is unfair in that a considerable part of the additional energy required over the theoretical figures is used to eliminate the impurities which accompany the iron in the ore: a perfectly justifiable criticism and one that makes it necessary to review in somewhat greater detail not only the practice but the use to which we put the plant we presently employ. The major part of the problem is not indeed a reduction of pure iron oxide, but the separation in the best possible way of the iron from the accompanying impurities.

Consider the blast-furnace: as used today it is a dual purpose apparatus. It reduces and melts metallic iron and eliminates the major portion of the ore gangue, and, in this generalization, it also removes moisture and the volatile constituents of the ore. In the first of these capacities it is only one of several possible methods for the gaseous reduction and melting of metallic iron. In its second capacity, as an eliminator of unwanted materials, it requires careful re-examination from time to time as knowledge advances, and from a commercial point of view, more important still when capital costs and fuel costs rise, as they have done in many cases in recent years, at a relatively higher rate than the iron-bearing materials themselves. The relatively high thermal efficiency of the blast-furnace and the high outputs which derive from the facility with which it can be supplied with large quantities of raw materials in relatively short times is so readily accepted that some of its major disadvantages are often overlooked. One of these, from a metallurgical point of view, lies in the fact that, in its capacity as a concentration unit, the blast-furnace gives only an impure metal demanding the subsequent refining which we term steelmaking. In other words, the operations of steelmaking arise only from the inherent limits of blast-furnace chemistry.

There are other disadvantages, too, which I can perhaps conveniently chronicle at this point. The blast-furnace demands certain mechanical characteristics in the burden, in regard to size and so on, which are not always attainable except by preliminary preparation. Again, except in special cases, it can only function with coke as fuel, and, moreover, a coke that has mechanical and other properties not attainable from all coals. The ash and other impurities (*e.g.*, sulphur) are also carried forward to increase the total of impurities demanding elimination afterwards. Perhaps the most serious disadvantage of the blast-furnace today, however, is the high capital cost of each unit and its ancillary equipment.

Let us refer to each of these disadvantages in turn and consider what is being or what might be done to mitigate if not remove them entirely. So far as the comparative impurity of the product is concerned, there is just nothing that can be done within practic-

able limits to prevent the passage of excessive carbon, silicon, sulphur, and phosphorus into the molten iron. It is true that the composition of the resulting iron may be controlled within very wide limits by burden or practice changes, but the final product of the blast-furnace will still demand a subsequent refining operation. The next two disabilities can best be considered together, for there are certain features that are common to both, the outstanding one being the requirements in the mechanical size of the ore and coke. One cannot help reflecting sometimes on the very considerable amount of trouble that accrues to the operator because the blast-furnace operation requires the passage of a gas stream through an 80–90-ft. high cylindrical column of material. Apart from the well-recognized difficulty of making the column of material travel downwards with anything like a uniform movement through the furnace, there is the difficulty of maintaining a uniform flow in the ascending current of gases. There is probably no aspect of blast-furnace work on which more time has been spent and from which fewer practical improvements have emerged. This is indeed a very fine example of that type of problem whose apparent simplicity is only equalled by its intractability.

There are, however, at least two modern lines of attack which—whatever was the primary intention of the innovators—can be regarded as ways of overcoming the difficulties resulting from the mechanical condition of the burden: (i) the high-top-pressure furnace, and (ii) the low-shaft furnace. Both devices, if one may so style them, will certainly relax the limitations on mechanical ore size, whilst there may even be some prospect that they will cause relaxation of coke specifications, in regard to both size and hardness. The high-top-pressure blast-furnace can be regarded as the logical development of the blast-furnace process as it has been evolved to the present time, but the advantages of the low-shaft process are at present obscure.

The descriptions of existing plants leave one in considerable doubt as to the primary aim of the system. It might be primarily a means of smelting mechanically unsuitable materials, it would appear to be a vehicle for the application of oxygen in smelting, or it may be just another of those processes in which the by-product—in this case the gas of high thermal value—is more important than the iron itself.

It might even be regarded as an example of the apparently immutable natural law that ideas tend to move in circles. With the addition of the tonnage oxygen plant, the low-shaft furnace is suspiciously like the bloomery of five hundred years ago, from which it has been claimed that molten iron was first accidentally made; presumably by over-energetic blowing on the part of the operating personnel! The latest designs for low-shaft plant suggest that it is in process of competing with the standard blast-furnace unit in the matter of complexity and control gadgets, and it is indeed difficult to foresee that it should ever have anything but a very specialized use under peculiarly favourable circumstances. In any case, it would not appear to have any particular claim to supplant the blast-furnace in any major scheme of operations, although it might have a limited application under very special conditions as an ancillary unit in an integrated plant.

So far as the high capital charges associated with modern blast-furnace construction are concerned, it is obvious that this disadvantage can be minimized only by securing the maximum possible output from any one unit. This aspect of the matter deserves more detailed study. If it is accepted that the primary task of the blast-furnace is the production of iron, what proportion of the total operating effort should be devoted to the removal of gangue and/or volatile material from the ore? In all except those districts favoured with extremely rich ores, this problem is becoming more acute every day. Fortunately, a reasonable ascertainment can be made on which to base economic solutions.

It is generally accepted that even when pure ore is used the furnace must make a certain minimum quantity of slag to maintain regular working. There is, therefore, a maximum possible output obtainable from any given furnace, and this should obviously be the aim in all cases. In terms of practice, it requires 950 lb. of slag per ton of iron made, and, on ores low in volatile matter with coke of reasonable quality, a coke rate of 1400 lb./ton could be anticipated—the highest performance to be expected from the blast-furnace itself. This has, in fact, been achieved. In passing, it may be noted that the iron content of this burden is just over 52%.

Any increase in cost, over that attainable on this standard, as the result of poor ore represents the cost of gangue removal and/or furnace calcination. From the figures it is possible to deduce the amount of money that it would be permissible to spend on ore treatment to achieve this basic standard.

With certain ores it may not be practicable to concentrate to 52% of iron, but this does not destroy the validity of the proposed method. In such cases, the calculation would be made on costs determined from output with treated and untreated ore, including the capital charges.

The basic assumptions on which the ascertainments indicated can be made are relatively simple. They are :

(i) That the total coke burned per hour or other convenient time will be constant. (This may not, in fact, be possible with poor burdens, but the error it introduces, if any, is on the safe side)

(ii) That operating expense, including wages, maintenance, relining, and services will also be constant

(iii) That the capital charges per unit of time are constant. (The percentage to be used is for the accountants to determine.)

The sum of these items divided by the tonnage produced gives, of course, the cost per ton, in each case. The difference between these figures multiplied by the total tonnage after the ore treatment is the amount of money which may be spent on that treatment. From this sum must be deducted the capital charges of the ore-treatment plant to obtain the permissible figure for ore preparation. If the cost of ore treatment is less than the total, all the iron made will

be lower in cost than the standard; if the treatment absorbs all the difference, the iron cost will be unchanged. It may be of interest to note that, on certain low-grade ores, the permissible expenditure under conditions of modern production in Great Britain may be as high as 15*s.* per ton of crude ore, including capital charges on the treatment plant.

The difficult question of whether to dry or dry and calcine low-grade ore, where this is appropriate, may be approached in a similar manner, although such an arithmetical method does not take into account some of the technical advantages to be derived from the procedure.

Again, the need to agglomerate fines which accompany most ores or which arise in crushing the lump portion, must be considered. The cost of these operations—sintering, pelletizing, and the like—is in part offset by the advantageous effect of the treatment on furnace performance, but in general once again the inability of the blast-furnace to handle mechanically most forms of fine materials adds something to the final cost of the iron.

It is, unfortunately, much easier to determine both the technical and economic limits of the blast-furnace than to suggest alternatives which might replace it. The very suggestion that there might be an alternative is enough to produce a shudder of apprehension, particularly from those whose interest centres on existing or projected capital investment. Unless, however, we can satisfy ourselves that in its ancillary function as a remover of impurities it is the only possible method, we are bound to consider what other ways are available to us.

The electric blast-furnace can have only a limited application when power costs are specially favourable, and I have already mentioned the low-shaft furnace. These are but modifications with, at best, special applications. There is left, therefore, nothing but the gaseous reduction systems, which can be conveniently grouped under the general classification of ' direct ' processes.

There is probably no sequence of metallurgical operations which can be made to look so attractive on paper as low-temperature reduction, followed by the melting of the metallic sponge. The fact that so many established steel concerns all over the world have spent so much money on so many processes is in itself evidence of how desirable the aim is. That hundreds of thousands of pounds have been lost in the same way by investors without knowledge of the industry is perhaps regrettable, but perhaps understandable. The reasons for these numerous failures are not, in fact, obscure. Apart from the great difficulties of handling a pyrophoric material from medium to melting temperatures and of devising a continuous melting process, there remains the inherent difficulty of gangue removal and the attraction of molten iron for certain impurities in the gangue from all but the purest ores. These processes, to my mind, have no future unless the initial raw material is virtually pure oxide of iron. This conclusion is supported by the fact that it is only in those areas where pure ores are available, *e.g.*, in Sweden, that any real success has been achieved.

We may note, in passing, those sponge processes in which reduction is followed by magnetic separation. They are not, strictly speaking, direct processes but are beneficiation processes and should be judged not as steel producers but as a means of ore concentration. It is perhaps interesting to note that in practice they have underlined some of the difficulties I have mentioned as militating against success in the direct processes.

To sum up this part of my study: the blast-furnace is likely to retain its pre-eminence as a producer of metallic iron from the naturally occurring and variable materials until such time as ore-treatment processes provide a product which is virtually pure oxide. If ever that time comes, and it may not be as far off as the more earth-bound may think, there will surely come, too, something like a real revolution in the basic processes of our industry.

Meantime, the group of operations to which we apply the generic term ' steelmaking ' is still an important part of the ore/ingot cycle, so it is now possible to examine some of the limitations and possibilities for change and development which they present.

From the general picture I propose to exclude acid processes, not because I would deprecate their interest and importance, but simply because the greater part of the available raw materials throughout the world make them inoperable. The essential operations that we wish to perform in steelmaking are melting, of either scrap or cold iron, purification and final adjustment of composition to any given requirement, together with the elimination from the metal of the excess of the active agent, oxygen, which was required for purification: in more generally used terms—melting, refining, and finishing.

So far as plant is concerned, attention may be confined to converters, and open-hearth and electric furnaces. The fundamental difference between these methods is, of course, in the source of the heat units by which the high temperatures of steelmaking are provided and maintained. In some measure these differences are reflected in the type of work on which each unit is commonly employed. The converter obtains heat from the combustion of the unwanted impurities of the iron ; in the open-hearth this heat is also generated but, in addition, heat from extraneous sources is required and is obtained from the combustion of gaseous or liquid fuels, whilst the electric furnace, in effect, uses a very indirect form of heat energy.

A more detailed study, not only of sources of heat energy but of its use in each process, is of first importance in any consideration of the possible application of each method to the metallurgical work which steelmaking demands. With the information which it gives, we may more confidently consider the practicability of any modifications to existing practices which suggest themselves.

The most striking fact which emerges from a general thermal study of the three processes is that the basic Bessemer process is, without doubt, the most efficient thermally of the three methods. In this process the

total quantity of heat involved in a thermal balance, starting with and including the heat in the molten iron, is just under 30 therms per ton of steel produced. About 40% of this is carried into the converter in the molten iron and the remainder is developed by the chemical reactions of the process—combustion of metalloids, slag formation, and other exothermic reactions. So far as expenditure of heat is concerned, 50% of the total is carried out in the molten metal and a further 16% in the slag, whilst about 27% is irrevocably lost in waste gases and radiation. (These last, in fact, are less than 2% of the total.) The remaining 7% is accounted for by relatively unimportant endothermic reactions. If the heat taken into the system in the molten iron is ignored and the difference between it and the heat in the final metal and slag plus the heat required for endothermic reactions is accepted, a figure is obtained that represents the total thermal work to be done in the operation. This comes out at 54% of the heat developed in the process—a very satisfactory thermal efficiency for such a high temperature operation.

Unlike the basic Bessemer process, which follows almost uniformly standard practice, the figures for the open-hearth are, of course, affected by the type of practice and the variations in raw materials. Unlike the Bessemer process also, the main source of heat is extraneous. The total heat input of the open-hearth furnaces is obtained from two sources—the combustion of the fuel and the exothermic reactions taking place in the bath. The quantity of combustion, *i.e.*, extraneous heat, may vary from 30–60 therms per ton of steel before allowing for any heat recovery from waste gases used for steam raising or other purposes. The reaction heat depends, as just noted, on the initial bath composition, which, of course, determines the quantity of metalloids to be removed and the concomitant slag volumes. The heat developed, however, is always less than the total quantity required. A number of calculations covering a considerable range of practice, both as regards scrap/iron ratio and iron composition, show that the balance of heat to be supplied from external sources varies between 5·75 and 7·75 therms per ton of steel into the ladle in hot-metal practice. If some of these figures are compared with the extraneous heat that is supplied in actual practice, some interesting deductions can be made. The following figures give a few results in comparative form. I have, for obvious reasons, taken the phosphorus content of the iron as the classifying factor.

Phosphorus in Iron, %	Iron/Scrap Ratio	Therms per ton of steel	
		Process Heat Deficiency	Heat Supplied in Normal Practice
0·35	100	7·30	40
0·35	80 : 20	7·65	35
0·80	100	5·75	60
0·80	80 : 20	6·50	50

These figures are, of course, only indicative, but they do show that the thermal efficiency of the open-hearth is in general much lower than that of the basic Bessemer process. In the most favourable case, with the most suitable type of iron, more heat has to be supplied from external sources than the total heat required to make one ton of steel by the converter, which as was noted earlier is about 30 therms. The other interesting feature is that, although there is a smaller deficiency in process heat with the less-pure irons, more external heat is required. In other words, the process heat developed by the oxidation of the metalloids is greater, but the increase does not compensate for the increased work which has to be done in refining. This again shows the striking difference from the Bessemer practice, where any increase in phosphorus or silicon leads to an excess of heat in the charge permitting of scrap melting or other endothermic work.

It is perhaps outwith the general scheme of this review to discuss the reasons for these differences between the processes, but it is clear, even on casual consideration, that the direct oxidation in the converter, with the accompanying development of heat within the metal itself instead of transfer through a slag layer as in the open-hearth, must be one reason. The use of oxygen instead of oxides cuts out not only an endothermic reaction but some weight of cold material to be heated to furnace temperature. Again, a time factor intervenes: the total heat of combustion of the impurities is evolved in minutes in the one case as compared with hours in the other, and in a vessel where radiation losses and an absence of water cooling reduce heat wastage considerably. Also, the heat carried out in the hot gases from the converter will be less than that leaving the open-hearth per ton of metal, although some of the heat from the latter can be recovered.

It is not possible to give a figure for thermal efficiency for the open-hearth process which would cover all the variations found in practice, but one case may be taken as an example: an open-hearth charge with 20% scrap and 80% low-phosphorus iron containing about 0·6% of silicon, 1% of manganese, and 3·5% of carbon gives an efficiency of 22% on the same basis as that already taken for Bessemer operation.

No consideration of the open-hearth furnace would be complete without some attempt to evaluate its performance as a melting unit for cold material—chiefly scrap. This is so much an integral part of all open-hearth steelmaking that one would expect that the heat required to do this would be easily determined. The other variables are so great, however, that, for general consideration, only an empirical approach may be made. I think it would be agreed that on a charge with a scrap/iron ratio of 80 : 20 on good large modern furnaces, a heat requirement of 30 therms is attainable. (In all these figures I am ignoring fettling and standing times. They are, of course, very important but not relevant to this discussion.) It would seem reasonable to take this figure also as that for melting scrap of a normal type. Now the total heat content of one ton of almost pure iron at, say, 1650° C., including latent heat, is 14 therms, so that in this operation the thermal efficiency of the open-hearth is about 46%.

The electric furnace is so generally used as a melting and finishing unit that this is a convenient point at which to note its thermal performance. If power

consumption per ton of product from cold scrap is assumed to be 770 kWh. and the electrode consumption is 22 lb., part of the heat from the combustion of which accrues to the process, a heat equivalent of 29·4 therms is obtained—a figure very similar to that just given for melting in the open-hearth. The figures are hardly comparable, however, in that the kilowatt hours themselves represent about one third of the original heat units of fuel of a similar kind to that taken in my consideration of the other processes. To this serious blow to the basic economics of electric melting, must be added the high cost per therm of the heat derived from the electrode combustion due to the high cost of electrodes. It is, nevertheless, important to note that the thermal efficiency is of the same order in melting scrap as in the open-hearth furnace.

You will expect me now, no doubt, having touched on economics to this limited extent, to say something on cost per therm in each of the two major processes which I have considered. In the case of the open-hearth, whether the fuel be producer gas, mixed gas, or oil, this is straightforward—the cost per therm is known or can be based on known fuel values.

The cost of the ' fuel ' in this case is, of course, the cost of the iron used or, more precisely, the cost of the iron, silicon, carbon, manganese, and phosphorus from the combustion of which the heat is developed. The value of each of these items must, in this case, be taken at iron cost. The loss in blowing may be taken at 10% on normal practice, so that the cost of heat with pig iron at, say, £10 per ton would be 20*s*. The total heat developed, including heat of slag formation, is about 18 therms, so that the cost per therm is approximately 1*s*. 1¼*d*. This may seem a very high figure, but it must be considered with at least two things in mind : (*a*) It includes the loss of iron which would have gone into the slag in any case, and (*b*) the total heat required, 18 therms, is only about half of what would be required in the open-hearth furnace on a good burden, and one third of that needed for an indifferent one.

It is not my purpose here to discuss comparative costs of the Bessemer and open-hearth processes, but as it happens that most of the major remaining items of conversion cost (and particularly, be it noted, capital charges) are lower than for the open-hearth, case for case, it is entirely fallacious to discuss the Bessemer process as a high-cost process because of low yields or its derivative high cost per therm.

I have dealt in some detail with the thermal side of the steel processes, not only because I took the apparent differences between theoretical possibilities and practical achievement in these terms as a starting point, but because fuel costs, in the indirect sense of the term, have an increasingly important place in the economics of the industry.

The next step in seeking to decide what changes in practice are likely to come about in the relatively near future, is to look at the basic considerations which determine the selection of a steelmaking process.

Now that technical developments have ensured parity of quality between the basic Bessemer and open-hearth product, at least over the greater part of the range of commercial steels, it is permissible to consider the relative merits of these two methods, and possible variations of them, on metallurgical suitability and economics alone. What factors, then, should determine the process to be employed in any particular case?

The history of the steel industry, at least since 1879 when Thomas and Gilchrist evolved the basic process, would appear to suggest that the phosphorus content of the pig-iron, with or without scrap availability, has been the final determinant.

In Great Britain and on the Continent, where high phosphorus pig-iron is produced from local ore, the basic Bessemer process has been successfully and very generally adopted, whilst in other countries, for instance, America, where the average phosphorus content is relatively low (say up to 0·35%), the open-hearth has been accepted as the standard procedure. There can be little doubt that, for phosphorus over 1·7% and below 0·5%, the Bessemer and open-hearth processes respectively represent the correct practice. The doubtful cases are those in which the phosphorus content lies between those figures, *i.e.*, where it is higher than can be removed with the minimum permissible quantity of slag in the open-hearth and less than can be safely used in Bessemer converters.

It was for such cases that the tilting furnace, with its many procedural variations, was evolved and for which it is still extensively employed. The phosphorus and excess of other impurities can be conveniently got rid of by intermediate slag removal. The method, however, involves large units and relatively high capital charges, not only in furnaces but in ancillary plant. These, too, are not the only costs by which flexibility has been bought, as both maintenance and fuel costs tend to be high.

The most convenient and obvious way to handle the intermediate phosphorus irons is by the use of scrap. This, as we all know, is not the normal approach to scrap use either by individual companies or nationally! The reasons for what is, in effect, a distortion of the metallurgical economy need not detain us here: my concern is with the use of scrap for a specific purpose—the dilution of an otherwise unsuitable pig-iron to give as nearly as possible an ideal open-hearth burden so far as composition is concerned. Assuming that hot metal is available and accepting the cost of melting the cold material, there is every justification for using scrap as a diluent where the iron composition requires it.

Perhaps, at this point, I may digress to place scrap in its proper perspective so far as this Address is concerned. The existence of scrap adds nothing, in the widest sense, to the ore/ingot iron balance sheet. It is the usual practice today to describe furnace- or mill-scrap as circulating scrap to distinguish it from the demolition of old plant and buildings. All scrap is circulating in the true sense, no matter whether it be ends from ingots or blooms made an hour earlier, from ship plates rolled the month before, or from obsolete tram rails from the very first basic Bessemer blow made on the North East coast. A certain minimum percentage of new iron from ore is an essential

foundation for any soundly based national steel economy. The achievement of this percentage may be delayed by fortuitous circumstances of various kinds, but, if the long-term balance sheet of iron units is not finally balanced, then a reduction in the national total of steel production is inevitable. I am concerned here, however, not so much with these elementary truths as with the best use of scrap in general steelmaking practice: how best to return the iron which it contains to the steelmaking cycle.

The first claim on scrap should be to assist in bringing the intermediate phosphoric irons into the most economic open-hearth production. The intelligent use of scrap, within one works perimeter or nationally, can only be achieved if one knows all the circumstances of each case. A basic Bessemer producer would use his iron production primarily for steelmaking by that process, but in his subsequent mill operation he would have at least 25% of his ingot production available as scrap. Assuming his Bessemer steel production to be large enough he would then have a volume of scrap sufficient to justify open-hearth operation. The open-hearth capacity would be determined by the nature of the pig-iron available to 'marry up' with this scrap. I have taken the case of a single producer, but similar principles could be applied to a national economy. I suggest, in other words, that a balanced steel production economy should be so integrated that all the available materials are used to give the maximum efficiency in any or all of the steelmaking processes employed. This condition, in fact, existed in Germany before the last war.

It must be admitted that, not only in Great Britain but in many other countries, the general pattern of operations does not work out in any close conformity to that just outlined, but that does not invalidate the statement of the ideal.

Much of the medium and higher phosphorus iron used in open-hearth practices today would be more economically converted into steel by raising the phosphorus at the blast-furnace and converting it by the basic Bessemer process, or by one of its latest modifications. This would indirectly assist in a more satisfactory scrap distribution.

It may be considered that, in basing process selection on the phosphorus content of the iron, a more general difficulty is evaded—the steelmaking burden which has been so aptly termed 'metallurgical load'. The trend of development today is all towards a preliminary operation to overcome the handicaps which excessive quantities of silicon, phosphorus, and carbon impose on them.

The right place to deal with metallurgical load, if it can be done, is obviously at the point of origin—the blast-furnace. The possibilities of improvement there, however, are limited. Even when the blast-furnace operation is impeccable the steelmaker finds himself faced with the problems of removing large quantities of silicon, or alternatively sulphur, to say nothing of the inevitable carbon and phosphorus. It does not contribute anything to the solution of the difficulties to remind him that the refining stage of steelmaking is, in fact, just the removal of metallurgical load! There is no doubt that the more work that is done by a steel process in refining, the longer will it take and the lower will be the output, to say nothing of the additional cost incurred in fluxes and fettling and other materials, and the additional slag volumes which are produced. It is for these reasons that, in recent years, there has been an increasing tendency to insert between the blast-furnace and the steel-furnace an intermediate stage, the object of which is to reduce the work to be done by the steel-furnace and increase its output.

This general outline covers such intermediate practices as mixer refining, slag washing, and duplexing. The result of such steps is to supply the open-hearth or electric furnaces with the metal best suited to give ideal control and high output conditions. These furnaces then become little more than finishing units. For instance, the results of converter/open-hearth duplexing can be quite dazzling so far as outputs are concerned, and, if maximum output from any given furnace were all that were required, the practice has everything to commend it. As a production operation to convert iron of a given composition to steel, however, it must be examined on a broader basis than mere output rate alone. If the composition of the original iron—or, more generally, of the furnace burden, which is the same thing—is modified by reducing or even wholly eliminating silicon and phosphorus and most of the carbon, the final steelmaking operation is speeded up and costs are reduced, but the cost of eliminating these elements, including capital charges, must be offset against the savings at the finishing furnace. We have not, in effect, been relieved of the work and cost of removing the unwanted elements—we have only transferred the work elsewhere.

It is desirable, in the first place, to estimate the order of savings which can be made in the open-hearth or electric furnace when operating in conjunction with the converter or other pre-refining unit. In addition to increased outputs, the savings which result are in fuel and other costs. The cost which may be incurred to give the final steel at the same or lower cost can be computed in a similar manner to that suggested earlier for determining the permissible cost of ore beneficiation. Without going into detail in too many cases, it is worth noting that the savings in power and electrode cost in converter/electric-furnace duplexing are such as to make the electric furnace a very attractive and efficient finishing unit, especially where a high degree of quality control of the product is desirable.

I propose only to note in passing those minor intermediate operations, which are frequently employed to improve the metallurgical load, but which do not involve additional steelmaking plant. These include mixer refining for silicon, with or without partial carbon removal, and the use of air or oxygen in hot-metal transfer ladles—a practice recently adopted with some success in basic Bessemer steelmaking.

The use of oxygen in accelerating the normal steelmaking processes is really a special case of these same developments which, as it happens, has rather wider applications. In addition to increasing the tons per hour in normal work, it permits of the relatively easy attainment of very low carbon content in the open-hearth or electric-furnace bath where these are

necessary for alloy steels of certain qualities. It must never be forgotten, however, that high outputs are only worthwhile if the methods of obtaining them are followed by lower final costs.

There is one further aspect of steelmaking (it applies to all processes) in which we are entitled to expect changes: I refer to finishing.

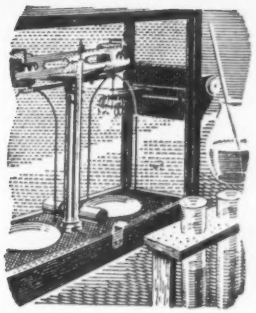
Ever since the addition of Mushet's ferro-manganese saved the Bessemer process from failure, this aspect of steelmaking has received intensive study—a study which is still continuing—but there is little doubt that the perfect steel from this standpoint is yet to be made, at least in regular quantities. We use the term deoxidation when, in fact, except perhaps in the case of electric-furnace metal, we do not so much remove the oxygen left over from refining or picked up from blast or furnace atmosphere, as leave it in the steel in another form. We perhaps rid the steel of the evil effects of free FeO, but, in so doing, leave in the metal non-metallic inclusions which of themselves have a detrimental effect on its properties. We invoke theories and adopt practices based on coalescence and flotation: we arrange alloys of such a composition that the final inclusions should be both fusible at the finishing temperatures and easily floated off, and yet today the major problem is still with us: How are we to get fully deoxidized clean steel? There is no sphere in which, to my mind, more progress remains to be made than in this single operation. But surely after everything has been done with elements and combination of elements—all of them avid for oxygen—standing times and what not, it is time we asked ourselves: Is there not perhaps another line of approach demanding, no doubt, new techniques which would give more satisfactory results?

During the past twenty years we have been achieving the aim in the laboratory with vacuum fusion. Is it too much to expect that this may yet be applied to the ladle or in the mould? The whole train of ills which follow from the inclusion of solid oxide particles from the usual deoxidants would disappear if we could use a deoxidizer which gave a gaseous end product, as carbon does in a rimming steel. It may be considered that degasification of the heat may be a more difficult operation than removing fine solid particles, but all laboratory experience suggests that it is the easier of the two—in the laboratory.

You may feel that, in the consideration of the various themes on which I have been talking, there is less of forward-looking prophecy than personal assessment of immediately possible changes, and still less of impending revolution. This, I think, is inevitable unless or until we can at least handle the seeds of any potential revolution. It may be, of course, as has been said of Britain, that the industry has had its revolution but that it has escaped most people's notice.

I must point out, however, that I have suggested to you what some of these seeds might be; for instance, the production of pure iron-oxide from impure ores and deoxidation by vacuum fusion. This may seem to you to be idealistic nonsense, but, if it does, I would remind you of the reason once given for Henry Ford's contempt of experts—"*They were never on familiar terms with the impossible.*"

Strain Ageing of Mild Steel



EFFECTS OF VANADIUM OR CHROMIUM ON THE STRAIN AGEING OF RIMMING STEELS

By W. R. D. Jones, D.Sc., F.I.M., and G. Coombes, Ph.D.

SYNOPSIS

This paper describes the effects of small amounts of vanadium and chromium on the strain ageing, rimming action, and mechanical properties of low-carbon rimming steels. Results are given for vanadium-treated rimming steels made on a laboratory scale and on a works scale by basic open-hearth and basic Bessemer processes. It is shown that rimming steels that do not strain age at 100° C. can be made by the addition of small amounts of vanadium. Laboratory experiments with chromium steels show that chromium, in amounts up to 0·5 %, is not effective in eliminating strain ageing.

An explanation for the effects of vanadium, based on thermodynamic data, is put forward and the results are discussed with reference to the dislocation theory. 754

EPSTEIN[1] has claimed that the addition of 0·03–0·15% of vanadium and/or 0·3% of chromium to a rimming steel confers a high resistance to strain ageing without seriously affecting the rimming properties of the steel. Epstein, Cutler, and Frame[2] have published results obtained with vanadium-treated rimming steels which give some support to this claim. In addition, Richardson[3] has concluded from thermodynamic data that if vanadium and chromium are added to a rimming steel in the amounts suggested by Epstein, the vanadium may, and the chromium will, leave an effectively rimming steel. This paper is an account of experiments carried out on rimming steels containing vanadium and chromium in amounts similar to those in the steels described by Epstein.

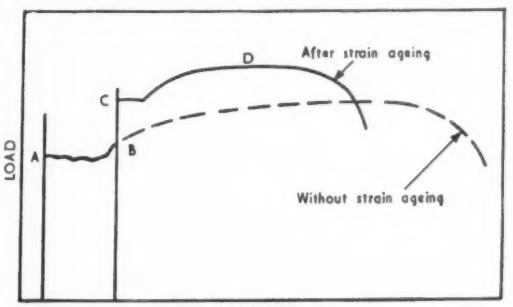
PRELIMINARY INVESTIGATION

An investigation has been carried out to determine a test that would measure both the extent and rate of strain ageing, and which would also describe the behaviour of the steel in regard to the return of the yield point. The tensile test was chosen as the basis, because it measures the yield point, and a strain before ageing equivalent to 7½% extension was chosen as being the minimum that was certain to stress most steels completely through the yield point.

Tensile specimens (B.S.S. 485: 1934) were machined from 20-S.W.G. bright-annealed sheets of an open-hearth steel (*V*) and a Bessemer steel (*X*). Each specimen was extended autographically by 7½%, removed from the testing machine, and given a predetermined ageing treatment. This was followed by quenching in water and restressing immediately to fracture. The ageing temperatures investigated were room temperature (approx. 19° C.), 60°, 100°, 150°, 200°, 250°, 300°, 400°, and 450° C. Suitable times were chosen to give ageing up to a maximum value at each temperature. For periods longer than ½ hr., specimens were aged in an air oven, but for shorter periods the specimens were aged at temperatures above 200° C. in a salt bath, at 150° C. in an oil bath, and up to 100° C. in water.

Figure 1 shows the typical load-extension curve of a steel during the 7½% extension before ageing and the curve obtained after the ageing treatment when the specimen is tested to fracture.

On ageing, the yield point *C* appears at a value higher than the load at 7½% extension *B*. The maximum load after ageing is also higher than the maximum load of specimens that have not been aged. Curves have therefore been drawn for each temperature of ageing in which two functions are plotted against the logarithm of the ageing time.



A = Lower yield point of annealed steel
B = Load at 7½% extension before ageing
C = Lower yield point after ageing
D = Maximum load after ageing

Fig. 1—Effect of strain ageing on the load-extension curve of an annealed rimming steel

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Dr. Jones is Professor of Metallurgy at the University College of South Wales and Monmouthshire, and Dr. Coombes is a research and development metallurgist with Edward Curran Engineering, Ltd., Cardiff.

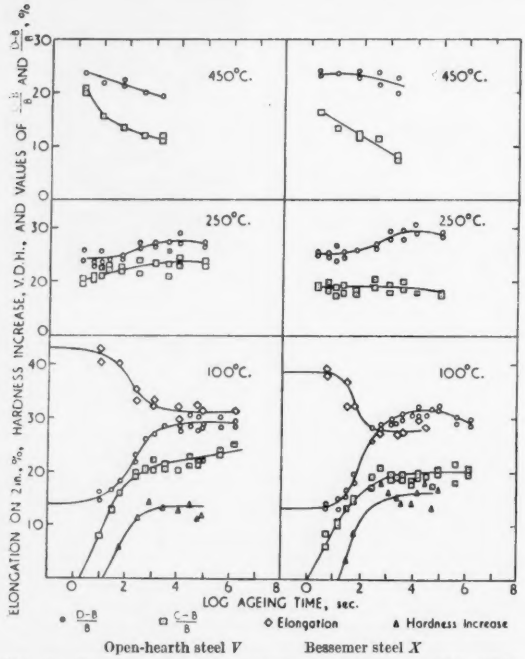

Fig. 2—Strain ageing of steels *V* and *X* at 100°, 250°, and 450° C. Amount of strain before ageing was 7½%

These functions, which were chosen because they are independent of mensuration errors, are:

(i) $(C - B)/B$, which gives a measure of the increase in yield strength on ageing expressed as a percentage of the load at 7½% extension

(ii) $(D - B)/B$, the increase in which gives a measure of the increase in maximum load on ageing expressed as a percentage of the load at 7½% extension.

Curves showing the effects of ageing temperatures of 100°, 250°, and 450° C. on these functions are given in Fig. 2. The results obtained show that 100° C. is the most suitable temperature to test for strain ageing, and that a measure of the rate of strain ageing is most conveniently obtained by determining the time required for the measured function (*e.g.*, $(C - B)/B$) to attain half its maximum value. The procedure finally adopted is as follows:

(i) Extend tensile specimens by 7½% in a machine fitted with an autographic recorder

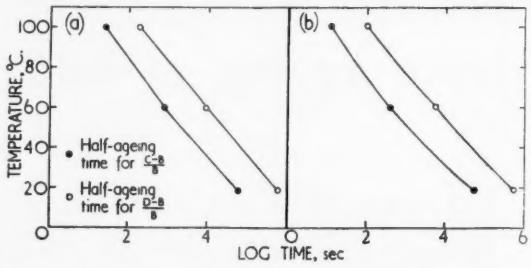

Fig. 3—Variation of half-ageing time with ageing temperature for (*a*) steel *V* and (*b*) steel *X*

(ii) Age at 100° C. for a series of times up to 24 hr. to obtain a complete ageing curve (as in Fig. 2)

(iii) Reload to fracture

(iv) Measure $(C - B)/B$, the increase in $(D - B)/B$, and the half-ageing time (sec. at 100° C.) for $(C - B)/B$.

It is considered that when $(C - B)/B$ and the increase in $(D - B)/B$ are nil, the steel will not exhibit strain ageing at normal temperatures. In addition, the longer the half-ageing time at 100° C. is, the more slowly will the steel strain age at normal temperatures (*see* Fig. 3).

The loss of ductility of a steel during strain ageing can be correlated with the function $(D - B)/B$ and with the increase in hardness, but not with the function $(C - B)/B$ (*see* Fig. 2).

In addition to tensile tests, a large number of hardness measurements have been made on the steels examined, which show that the hardness test is useful only as a rapid qualitative test for strain ageing.

To assess the effectiveness of the adopted test for strain ageing, an experiment was made to investigate the effect of different rates of cooling on the strain ageing of a commercial rimming steel (ingot 1, Table I). Tensile specimens of cold-reduced 20-S.W.G. sheet were annealed at 690° C. for 20 hr. in boxes of welded steel plate ⅛ in. thick. Certain of these were furnace-cooled and the remainder were air-cooled. When cold, the specimens were given the test for strain ageing, and the results obtained (*see* Table II) showed that increasing the rate of cooling increased both the extent and the rate of strain ageing. Cottrell and Leak[4] have recently obtained similar results with a low-carbon iron.

THE LOWER YIELD POINT

The specimens of steels *X* and *V* that were tested

Table I

VANADIUM STEELS MADE ON A WORKS SCALE*

Type of Steel	Ingot No.	C, %	Mn, %	S, %	P, %	V, %	V Added, %	V Recovery, %	Rim in Slab, %		Ingot to Slab Yield, %
									Top of Ingot	Middle of Ingot	
Basic Open-Hearth	1	0·065	0·34	0·024	0·018	0·000	0·000	...	46	39	87
	2	0·075	0·37	0·027	0·016	0·042	0·053	79	45	42	83
	3	0·070	0·37	0·021	0·028	0·090	0·107	84	43	44	83
	4	0·075	0·35	0·020	0·020	0·105	0·16	66	26	34	75
Bessemer	5	0·065	0·36	0·033	0·033	0·055	0·16	34	36	30	76

* The analyses were carried out at Ebbw Vale Steel Works

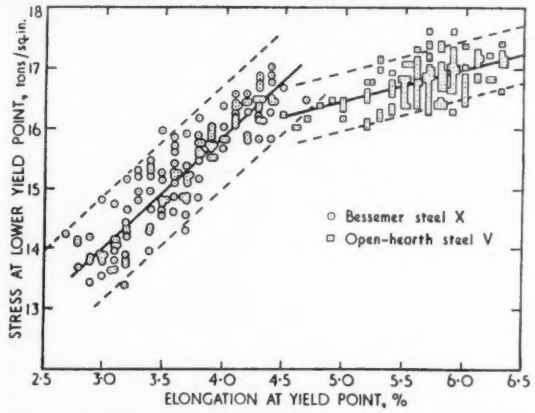

Fig. 4—Variations of yield-point behaviour in specimens of steels *V* and *X*. Dotted lines show the maximum deviation from the full lines due to the estimated experimental error

under standardized conditions in the preliminary investigation showed large variations in yield-point behaviour, even when machined from adjacent positions in the same sheet. These variations are recorded in Fig. 4, which shows that for each steel there exists a linear relationship between the percentage elongation and the stress at the lower yield point. The variations in yield point are probably due to local variations in grain size in the sheet. They can be compared with results obtained by Edwards, Jones, and Walters,[5] who found that in two steels, treated to produce different grain sizes, a linear relationship existed between yield elongation and yield point, and that the relationship was identical for both steels. However, it seems probable from the results obtained in the present work that different relationships, probably due to different rates of work hardening, can apply to different steels.

VANADIUM STEELS

A series of rimming steels containing 0·13% of carbon and 0·3% of manganese has been made in a 16-lb. H.F. furnace. Up to 0·25% of vanadium was added, as 54% ferro-vanadium, to these steels, which were teemed into a cast-iron round-bar mould and subsequently forged and rolled into 20-S.W.G. hard strip. This was bright-annealed at 680° C. for 20 hr., and tensile specimens cut in the direction of rolling were tested for strain ageing. The effect of vanadium on strain ageing, tensile properties, and grain size is shown in Fig. 5. Its effect on rimming action was assessed from the behaviour of the steels when teemed

Table II

EFFECT OF RATE OF COOLING ON THE STRAIN AGEING OF A COMMERCIAL RIMMING STEEL

Annealing Temp., °C.	Rate of Cooling	$\frac{C-B}{B}$	Increase in $\frac{D-B}{B}$	Half-Ageing Time for (C − B)/B, sec. at 100° C.
690	In air	25	17	35
690	In furnace	21½	11	63

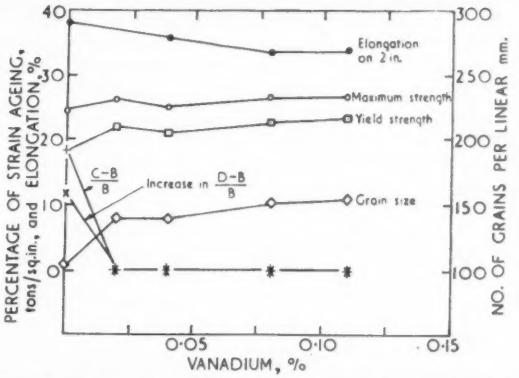

Fig. 5—Effect of vanadium on the tensile properties, grain size, and strain ageing of 0·13% C rimming steels made in the laboratory and annealed at 680° C. for 20 hr.

and from the blowhole distribution of the ingots produced. Additions of up to 0·1% of vanadium had no appreciable effect on rimming action, but greater amounts caused considerable deoxidation.

Following these laboratory experiments, several ingots of vanadium-treated rimming steel were made.* Four 10-ton ingots were teemed consecutively from a ladle of open-hearth steel. In addition, one 8-ton ingot of Bessemer steel was teemed. Vanadium was added, as 49% ferro-vanadium, to the mould during teeming. The chemical composition of these ingots and the percentage recovery of vanadium are given in Table I.

Ingot 1 rimmed vigorously, and ingot 2 showed a reduced but adequate rimming action. Ingots 3, 4, and 5, however, showed very weak rimming actions. The rim dimensions of these steels were measured at the slab stage, and are given in Table I, which also gives the ingot slab yield. These results indicate that all the ingots made possess structures that are typical of rimming steels.

* At the Ebbw Vale works of Richard Thomas and Baldwins, Ltd.

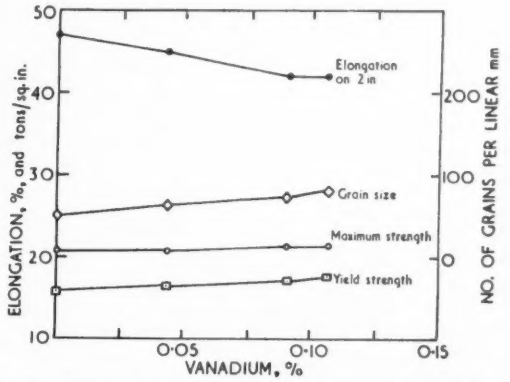

Fig. 6—Effect of vanadium on the properties of an O.H. rimming steel bright-annealed at about 680° C. (average value of samples from positions corresponding to the top, middle, and bottom of each ingot)

Ingot 1 was hot-rolled in accordance with normal works practice, *i.e.*, the slab was hot-rolled down to 0·1 in. thick and then water-sprayed before being coiled at 677–693° C. The vanadium steels, however, following the recommendations of Epstein, Cutler, and Frame,[2] were not water-sprayed after hot-rolling, and were coiled at 770–820° C. The vanadium steels cannot therefore be compared directly with the steel containing no vanadium.

The hot-rolled strip was pickled, cold-reduced to 20 S.W.G., sheared into sheets, and bright-annealed at about 680° C. for 20 hr. The sample sheets for testing, which were packed together at the centre of the furnace, were tested for strain ageing and examined under the microscope. The tensile properties and grain size of the open-hearth steels are given in Fig. 6, and the results of the strain-ageing test in Table III.

The microstructures of the steels showed ferrite with a small amount of spheroidized carbide. The sheet from ingot 1, which was water-sprayed after hot-rolling, had a uniform ferritic grain size, but the sheet from the vanadium-treated open-hearth ingots, which were not water-sprayed after hot-rolling, had large grains at the surface. Typical microstructures showing these effects are given in Fig. 7.

The annealed 20-S.W.G. sheets were temper-rolled, and alternate sheets taken from positions down each ingot of open-hearth steels were pressed 11 days later.* The remaining sheets were pressed 35 days after temper-rolling, when it was found necessary to roller-level the sheets from ingot 1 before pressing to eliminate the yield point, which had returned by strain ageing. The results of these operations are given in Table IV.

* At the Pressed Steel Co., Ltd., Oxford.

Table IV

RESULTS OF PRESSING OPERATION ON VANADIUM-TREATED O.H. STEEL SHEET

Ingot No.	V, %	Time between Temper-Rolling and Pressing, days	No. of Pressings Made	Good Pressings, %
1	0·000	11 35	303 302*	83 88½*
2	0·042	11 35	251 256	96½ 100
3	0·09	11 35	285 282	83 86
4	0·105	11 35	260 267	89 98½

* After roller-levelling

CHROMIUM STEELS

A number of chromium-treated rimming steels containing 0·06% of carbon and 0·3% of manganese with up to 0·45% of chromium were made and examined, using the same procedure as that for the laboratory-prepared vanadium steels already described. The effect of chromium on tensile properties and strain ageing is shown in Table V. Additions of up to 0·2% of chromium had little effect on rimming action.

Table III

STRAIN AGEING OF VANADIUM STEELS MADE ON A WORKS SCALE

Ingot No.	Position of Sample	V, %	N, %	$\frac{C-B}{B}$	Increase in $\frac{D-B}{B}$	Half-Ageing Time for $(C-B)/B$, sec. at 100° C.
1	Top			18	7	60
	Middle	0·00	...	19	8	66
	Bottom			19	7½	56
2	Top	0·029*	0·0075*	0	0	...
	Middle	0·026*	0·0050*	0	0	...
	Mid-bottom	0·028*	0·0075*	13½	0	250
	Bottom	0·030*	0·0045*	0	0	...
3	Top			0	0	...
	Middle	0·09		0	0	...
	Bottom			0	0	...
4	Top	0·105		0	0	...
	Middle			0	0	...
	Bottom			0	0	...
5	Top	...	...	18	13½	19
	Middle	0·34*	0·012*	18	13½	21
	Bottom	...	...	17	7	100

* These samples were analysed by B.I.S.R.A.

Table V

TENSILE AND STRAIN-AGEING PROPERTIES OF CHROMIUM STEELS MADE ON A LABORATORY SCALE

Cr, %	Yield Strength (Tons/sq. in.)	Maximum Strength (Tons/sq. in.)	$\frac{C-B}{B}$	Increase in $\frac{D-B}{B}$	Half-Ageing Time for (C − B) B, sec. at 100° C.
0·027*	16·7	22·7	20	12½	25
0·041*	16·8	22·4	19	14	10 (approx.)
0·062*	16·9	22·6	18	11	25
0·11	16·2	22·2	19	11½	50
0·19	16·6	22·2	13½	2½	100
0·25	17·1	22·5	12	3	250
0·44	18·3	23·5	7½	0	5000

* These samples were analysed by B.I.S.R.A.

The effect of annealing temperature on the strain ageing of vanadium steels was determined from tensile specimens of a number of cold-reduced 20-S.W.G. vanadium steel sheets, which were annealed at temperatures from 650° to 930° C. for suitable times and tested. The results obtained are summarized in Table VI.

To determine the effect of ageing temperature on strain ageing, vanadium steel specimens that did not strain age after 24 hr. at 100° C. were extended 7½%, aged at 200° and 250° C., and then stressed to fracture. Results obtained are given in Table VII, and they show that vanadium steels which do not strain age at 100° C. may do so to a limited extent at higher temperatures, the extent being independent of vanadium content and mainly dependent on the time and temperature of ageing.

Table VII

EFFECT OF AGEING TEMPERATURE ON THE STRAIN AGEING OF VANADIUM STEELS

V, %	Ageing Temperature, °C.	Ageing Time, hr.	$\frac{C-B}{B}$	Increase in $\frac{D-B}{B}$
0·023	100	24	0	0
	200	3	6	1½
0·08	100	24	0	0
	200	3	5	2
	250	½	8	4
	250	24	12	3½
0·11	100	24	0	0
	200	3	5½	2
	250	½	8½	4½

DISCUSSION OF RESULTS

In a typical open-hearth rimming steel, the minimum amount of vanadium required to eliminate strain ageing at normal temperatures is probably about 0·03%, and an addition to the mould of about 0·05% (as ferro-vanadium) is enough to achieve this. This amount of vanadium is not sufficient to affect the rimming action seriously. The addition of chromium in amounts of up to 0·5% to rimming steels

Table VI

STRAIN-AGEING PROPERTIES OF VANADIUM STEELS ANNEALED AT DIFFERENT TEMPERATURES

Steel	V, %	N, %	Temperature of Annealing, °C.	$\frac{C-B}{B}$	Increase in $\frac{D-B}{B}$
A	0·00	Approx. 0·005	690	21½	11
			750	23½	15½
B	0·00*	0·004*	650	18½	11½
			750	18	11½
C	0·011*	0·0065*	650	13	4
			680	16	9
			750	16½	7
D	0·015*	0·0075*	650	14	7
			680	16½	9
			750	17½	10
E	0·029*	0·0075*	650	5	0
			750	10½	0
F	0·023*	0·0065*	680	0	0
			930†	16	13
G	0·08*	0·0075*	680	0	0
			930†	8	4

* These samples were analysed by B.I.S.R.A. † Different cooling rate after annealing

is not effective in completely eliminating strain ageing at 100° C. However, up to about 0·2% of chromium can be added to rimming steel without affecting the rimming action to any extent.

The results suggest that, to obtain microstructures and properties similar to those of plain-carbon rimming steels, vanadium-treated steels should be

(i) Water-sprayed after hot-rolling (normal practice for rimming steels)
(ii) Annealed at a slightly higher temperature than is usual for rimming steels, to counteract the slight grain-refining action of vanadium.

Results also suggest that small amounts of vanadium have little effect on the deep-drawing and pressing qualities of rimming steel.

Richardson[3] has examined the thermodynamics of the reactions of the carbides, oxides, and nitrides of chromium and vanadium, and from this information the British Iron and Steel Research Association has produced curves showing the equilibrium between vanadium, nitrogen, and vanadium nitride in iron. Figure 8 is typical of these; it relates to iron containing 0·006% of nitrogen with different amounts of vanadium. The results obtained in the present work for the strain ageing of vanadium steels can be qualitatively correlated with these curves. Steels that theoretically contained no free nitrogen at the annealing temperature did not strain age, whereas

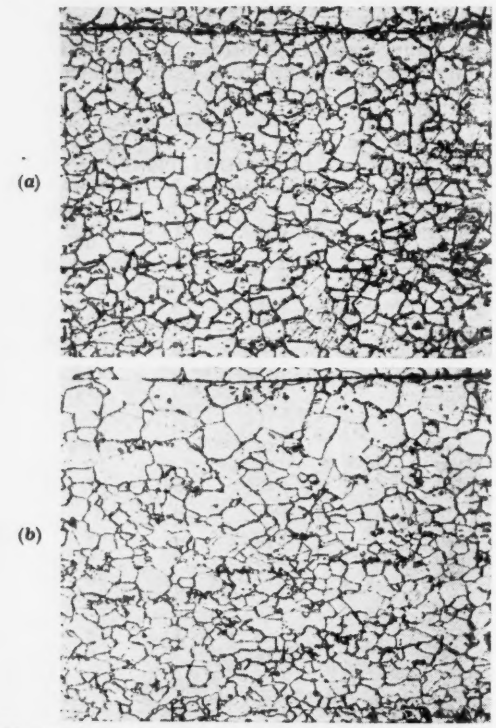

Fig. 7—Photomicrographs of 20-S.W.G. sheets of O.H. rimming steel, showing (*a*) uniform grain size in steel containing no vanadium (ingot 1), which was water-sprayed after hot-rolling, and (*b*) large surface grains in a vanadium-treated steel (ingot 2: V = 0·09%), which was not water-sprayed. Etched in 5% nital for 45 sec. × 100

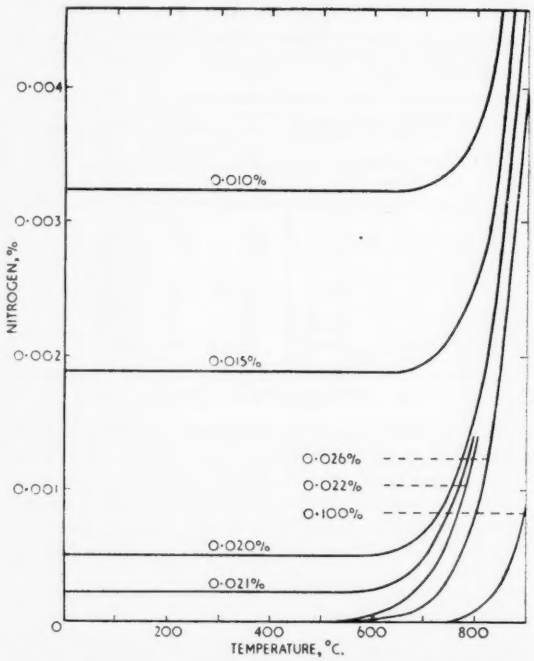

Fig. 8—Nitrogen content of iron in equilibrium with vanadium nitride (total nitrogen = 0·006%). Figures on curves refer to total vanadium content

those theoretically containing free nitrogen were susceptible to strain ageing. In addition, raising the annealing temperature of vanadium steels (*see* Table VI) increased the susceptibility to strain ageing in accordance with the thermodynamic data.

A quantitative correlation is, however, not possible; this is probably due to one or more of the following factors:

(i) With the techniques of chemical analysis at present available, a sufficiently accurate value cannot be obtained for the nitrogen content of vanadium steels. This is shown by Table VIII, which gives values for the nitrogen content of vanadium steels obtained by vacuum-fusion and chemical-distillation methods. These analyses were carried out by B.I.S.R.A.
(ii) The steels tested contained certain other elements in amounts comparable with that of the vanadium content. Several of these, *e.g.*, chromium and molybdenum, might possibly be combined with nitrogen in the steel.
(iii) The extent to which the equilibrium between vanadium and nitrogen is maintained on slow-cooling from the annealing temperature is not known.

It follows from these considerations and also from results obtained in this work that the addition of vanadium to rimming steels containing fairly large amounts of nitrogen (*e.g.*, Bessemer steels) is not practicable, since the amount of vanadium that would be required to combine with all the nitrogen present to produce a non-ageing steel would deoxidize the steel enough to affect the rimming action seriously.

The dislocation theory suggests a possible mechanism for the action of vanadium on strain ageing.

Table VIII

NITROGEN CONTENT OF VANADIUM STEELS DETERMINED BY VACUUM FUSION AND CHEMICAL DISTILLATION

No. of Steel	V, %	N, %	
		Vacuum Fusion	Chemical Distillation
N	0·000	0·004	0·004
O	0·025	0·005	0·0066
P	0·028	0·006	0·0074
Q	0·11	0·007	0·0086

Vanadium steels exhibit a pronounced yield point, and so the dislocations present must be anchored by 'atmospheres' of the same nature as those that are suggested as existing in a plain-carbon steel.[6, 7] It follows that these atmospheres are formed of carbon and/or nitrogen atoms and that the action of vanadium in eliminating strain ageing at 100° C. must be due to its preventing the carbon and/or nitrogen atoms in solution in the ferrite from diffusing through the lattice after plastic deformation.

Cottrell and Leak have suggested (*loc. cit.*,[4] p. 306) that "for making 'non-ageing' steel, the best procedure would seem to be to remove the nitrogen from solution by the addition of an element such as aluminium, with a strong affinity for it, and to remove the carbon from solution by a preliminary heat treatment at, say, 200° C." It is probable, from thermodynamic considerations, that nitrogen is present in non-ageing vanadium steels entirely as vanadium nitride. However, it is not feasible to suggest that all this vanadium nitride is present entirely as a separate phase. If this were true, the yield point observed could only be caused by atmospheres of free carbon atoms and the steel would be susceptible to strain ageing.* Accordingly, it follows that the atmospheres which anchor dislocations in the steel are formed of nitrogen atoms chemically combined with vanadium atoms, *i.e.*, the atmospheres are composed essentially of vanadium nitride molecules. It also follows that no carbon can be present in solid solution in the steel. This gives support to the views recently expressed by Cottrell and Leak,[4] who have shown that in a slowly cooled low-carbon iron the carbon is precipitated as cementite and is not available to lock dislocations, which are then anchored by atmospheres of nitrogen atoms, *i.e.*, the amount of carbon remaining in solution is too small to contribute significantly to strain ageing.

Vanadium steels that contain enough vanadium to combine with all the nitrogen present, but which are annealed at a temperature high enough to cause dissociation of the vanadium nitride, strain age at 100° C.; in these steels, dislocations may be anchored by free nitrogen atoms that are not combined with vanadium atoms. Free nitrogen atoms may be able to diffuse rapidly through ferrite containing small amounts of vanadium, but vanadium nitride can diffuse only at a very slow rate. It would be expected from this that vanadium steels that are 'non-ageing' at 100° C. should strain age at higher temperatures. This effect has been observed experimentally (*see* Table VII).

* Gensamer and Low[8] have shown that carburized tensile test pieces of iron, previously decarburized and denitrogenized to show no yield point or strain ageing, strain age similarly to plain-carbon rimming steels when extended 10% in tension and aged for 3 hr. at 200° C.

CONCLUSIONS

Non-ageing rimming steels can be made by adding vanadium. The amount required depends on the nitrogen content, and in steels of high nitrogen content (*e.g.*, Bessemer steels) this would be enough to affect the rimming action seriously. However, in a typical open-hearth rimming steel, the residual amount of vanadium required is about 0·03%. This can be obtained by adding about 0·05% (as ferro-vanadium) to the mould during teeming, which has no serious effect on rimming properties. These results confirm the claim made by Epstein[1] for vanadium-treated rimming steels. However, the use of chromium to produce a substantially non-ageing rimming steel, as suggested by Epstein, is not effective.

Commercial vanadium-treated rimming steels can be heat-treated in the same way as plain-carbon rimming steels, but improved mechanical properties might be obtained by water-spraying after hot-rolling, and by annealing, after cold reduction, at a slightly higher temperature than that usual for plain-carbon rimming steels.

Vanadium probably inhibits strain ageing by combining with nitrogen in the steel to form vanadium nitride. This nitride dissociates at temperatures above about 700° C., and steels annealed at a high enough temperature become susceptible to strain ageing. The dislocation theory can provide an explanation for the mechanism by which vanadium inhibits strain-ageing.

Acknowledgments

The authors wish to thank Mr. W. Roberts and Mr. W. R. Bird, of Richard Thomas and Baldwins, Ltd., Ebbw Vale, and Mr. G. Murray, of the Pressed Steel Co., Ltd., Oxford, for their valuable co-operation in many directions. The work was supported financially by the British Iron and Steel Research Association, and the authors would like to acknowledge the helpful suggestions made by Mr. T. Dennison of the Metallurgy Division.

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BRITISH STEEL CASTINGS RESEARCH ASSOCIATION

The Research and Development Division of the British Steel Founders' Association has now assumed the status of an independent Research Association, and will in future be known as the British Steel Castings Research Association. At the present time it receives no grant from the Department of Scientific and Industrial Research, but is financed solely by the steelfounding industry.

The B.S.F.A. Research and Development Division was established in 1949, and in 1951, on the disbandment of the Steel Castings Division of the British Iron and Steel Research Association, it became the industry's sole organization for co-operative research. During 1950 a series of long-term research projects was initiated in various universities and, at the same time, arrangements were made at the B.S.F.A. headquarters in Sheffield for the provision of essential laboratory services, and also for space for research work to be undertaken by the permanent staff. In this way, and with the additional assistance of the laboratories and plant of several of its industrial Members, the Research and Development Division's immediate requirements in respect of service and research laboratory facilities were met.

During its first three years of operation, a wide field of steelcasting metallurgy and foundry technology has been covered, including problems related to industrial health, and in particular to steelfoundry dust suppression. Important advances have been made in relation to the non-destructive testing of steel castings. Research at the University of Durham and at the Imperial College of Science is in progress on the mechanism of freezing of steel in refractory moulds, and research on metal penetration and on surface finish in steel castings has been in progress in the University of Cambridge since 1950. The Association's research on the influence of moulding materials upon hot tearing in steel castings is to be made the subject of a paper to be presented before the American Foundrymen's Society in Chicago later this year.

The B.S.F.A. Research and Development Division established its first experimental unit—the Dust Research Station—in Sheffield in 1951. Further experimental units are now contemplated which will greatly extend the facilities for essential work on pilot-plant or full industrial scale.

The problem of translating the results of research and development into practice has been fully recognized by the Association since its formation. In this connection, much greater importance is attached to discussion and to direct demonstration than to the circulation of written reports. Discussion with industry takes place at all stages in the prosecution of a research project—through the medium of the Association's Specialist Panels and Standing Committees, and later through the Regional Discussion Groups, and with individual Member firms. Meetings of the Discussion Groups are attended not only by the senior technologists and shop superintendents but also by staff and operators from the foundry floor, upon whom ultimately so many of the results of research must depend for their application in practice. Discussion is supported by direct demonstration, this taking place in the Research Station or in Members' works, according to the nature of the development.

In line with previous policy, the British Steel Castings Research Association will maintain close contact with parallel associations concerned with foundry research and metallurgy in Great Britain and abroad. It is hoped that an increasing number of papers arising from the work of the Association will be published in this *Journal*.

The first Chairman of the Council of the Association is Mr. F. N. Lloyd, and its Director is Mr. J. F. B. Jackson, who has been Director of Research to the British Steel Founders' Association since 1949.

RECOMMENDATIONS TO AUTHORS

Submission of Papers

Authors who intend to submit papers for publication in the *Journal* are reminded that space is severely limited. Delay in publication can be avoided only by publishing more papers of shorter length.

A style of writing which is concise and yet clear in expression will be read with greater ease and understanding than one that is verbose and vague. In particular, the repetition of data in tables, figures, and text should be avoided.

Wherever possible the Editor will shorten a lengthy paper, but it is obviously in the interest of the author that he should consider any possible condensation before submitting his manuscript.

Authors are requested to prepare brief synopses of their papers, in a form suitable for abstracting.

Letters to the Editor

Authors are invited to submit short articles in the form of Technical Notes or Letters to the Editor. It is intended that these should be brief notes, describing some new method, apparatus, or important finding that may be of general interest, which do not require the preparation of a full paper or report.

They are intended to replace, rather than to augment, the short papers (2–3 pp.) that appear frequently in the *Journal*, and so to release space for presenting the results of more detailed investigations.

Authors submitting such notes for publication should clearly indicate that they are Technical Notes or Letters to the Editor. (An example is shown on p. 31 of this issue.)

Preparation of Manuscripts

The work of the editorial staff will be greatly assisted if authors follow the requirements of the Publication Committee set out below. The top copy of the manuscript should be submitted; a second copy, if available, is useful, for delay may be avoided when the paper is refereed.

(1) Manuscripts should be typed, in double spacing, on one side of the paper. Duplicated reports, unless printed on non-absorbent paper, cannot be accepted.

Mathematical expressions, Greek or other symbols, should be hand written, with ample allowance between typescript matter.

(2) Diagrams should be drawn in black Indian ink on tracing cloth. Bristol board, or stout drawing paper, and generally should be at least twice the size of the final reproduction, which will usually be at column width ($3\frac{1}{8}$ in.) or page width ($6\frac{1}{2}$ in.). All lettering should be written in pencil, either on the original drawing or preferably on a separate print (if a print is possible) or rough sketch.

(3) Photographs (unmounted) should be printed on glossy bromide paper to give sharp contrast. It is helpful to the Editor if authors indicate on the back of the print the important area of the photograph which is to be reproduced, as this enables the block to be made at the smallest size without unnecessary reduction. All diagrams and photographs should be numbered and should be accompanied by a list of captions attached to the manuscript.

(4) Tabular matter should be kept to a minimum and should not repeat data already shown graphically.

Assessment of Weldability by Rapid Dilatation Tests

By C. L. M. Cottrell, M.Sc.

SYNOPSIS

The transformation characteristics of a series of 34 experimental low-alloy steels have been examined in a rapid dilatometer, using a thermal cycle similar to that occurring in a known welding test. The steels were mainly of the manganese-nickel-chromium-molybdenum type, some containing copper. A commercial boron-molybdenum steel was also examined.

The results show that, when the steels are metal-arc welded under given conditions, a relationship exists between incidence of hard-zone cracking and the temperature for completion of austenite transformation during cooling.

A method is described by which the thermal cycle occurring in the heat-affected zone of a weld is simulated in a dilatometer specimen. This rapid dilatation test can be used for assessing the weldability of low-alloy steels without making a welding test. 742

It has been shown by Reeve,[1] Dearden and O'Neill,[2] and Ball and Cottrell[3] that the greater the hardness value produced in the heat-affected zone adjacent to metal-arc welds, the more likely are hard-zone cracks to occur. This has since been amplified[4] to show that the rate of cooling at 300° C. in the hard zone is important. The effect of joint rigidity (restraint) has been dealt with by Hanson and his co-workers.[5] The theory put forward by Hopkin[6] has shown the importance of hydrogen dissolved in the weld metal in the formation of these cracks. Work by Wheeler and Kondic[7] has indicated that, when a steel is heated to a high temperature and subsequently quenched, a martensite with inferior mechanical properties is produced.

It appeared from the work of several investigators[4, 6, 8–10] that the effect of hydrogen during the austenite–martensite transformation should be an important factor in the initiation of cracks in the hard zone. Following a suggestion by G. L. Hopkin, it was decided to determine the relationship between the temperature at which the austenite–martensite transformation takes place in certain alloy steels and the liability of those steels to this form of cracking.

The steels used in this investigation were of the Ni–Cr–Mo type, having three different levels of manganese, nickel, and chromium contents, giving a series of 27 steels; in addition, four steels containing copper and four with zero (residual) nickel content were used. A commercial boron–molybdenum steel that had shown good weldability was also tested. The results of the weldability tests on these steels have been published in a paper by Ball and Cottrell,[3] and are summarized in Table I, which gives also the physical properties of the steels in the normalized condition; their chemical analyses are given in Table II.

It will be seen from Table I that with the small fillet weld nearly all the steels gave hard-zone cracks, whereas several steels gave no cracking in the large fillet weld. It was therefore decided, as the first stage of the investigation, to simulate the cooling rate that occurred in the hard zones of both test welds, using a dilatometer in which the progress of the austenite–martensite transformation could be studied.

It is realized that these steels fall into one class, *i.e.*, low-carbon Mo-containing steels, and the results may therefore be restricted. It is, however, intended to extend the investigation to cover different types of high-carbon steel and molybdenum-free steel.

EXPERIMENTAL TECHNIQUE

To simulate the cooling cycle that occurred in the heat-affected zone of arc welds in a dilatometer specimen, a special experimental technique had to be evolved.

A tubular specimen was used, since this allowed high cooling rates to be produced by gas quenching. The specimen was 1 in. long × 0·225 in. outside dia. × 0·15 in. internal dia., the thin wall allowing high heating and cooling rates to be obtained. A dial-gauge dilatometer was used, the salient features of the construction being shown in Fig. 1. The whole dilatometer assembly was mounted horizontally on a heavy base plate, and was vibrated electrically to ensure the accurate following of specimen dilatation by the dial gauge.

For the measurement of temperature a chromel–alumel thermocouple was used. In a previous investigation[11] the thermocouple bead had been flash-welded to the steel. The same technique was tried in this instance, but it was found that the response was satisfactory only where the cooling rate was low. The thermocouple wires were therefore separately flash-welded to the mid-point of the internal wall of the specimen, about $\frac{1}{16}$ in. apart, thus making a

Report No. FM8/83 of the British Welding Research Association, received 5th January, 1953.

Mr. Cottrell is Assistant Chief Metallurgist (Ferrous) at the Association.

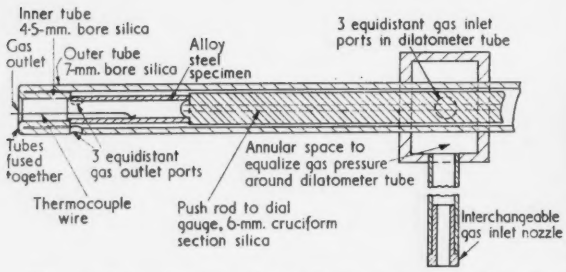
Inner tube
4·5-mm. bore silica
Gas outlet
Outer tube
7-mm. bore silica
Alloy steel specimen
3 equidistant gas inlet ports in dilatometer tube
Tubes fused together
3 equidistant gas outlet ports
Annular space to equalize gas pressure around dilatometer tube
Thermocouple wire
Push rod to dial gauge, 6-mm. cruciform section silica
Interchangeable gas inlet nozzle

Fig. 1—Arrangement of specimen and gas ports in dilatometer used for 1-in. long specimens

portion of the specimen the hot junction. This method proved to be satisfactory.

To indicate temperature, an instrument was used having a critically damped suspension and with a full-scale response time of 0·3 sec. For recording purposes the temperature indicator, together with the dilatometer dial gauge and a timer, were grouped together and photographed on 16-mm. film at 2–2½ frames/sec. The arrangement of the instruments is shown in Fig. 2, and the accuracy of final temperature measurement was about ± 1%.

For cooling the specimen, 'oxygen-free' nitrogen was used, containing about 10 parts of oxygen per million parts of gas. The quenching gas was admitted near the centre of the dilatometer tube, and was allowed to escape at both ends of the tube, thus maintaining the dial-gauge spindle in a region of low pressure. The gas was admitted to the dilatometer tube by means of three holes surrounded by an annular ring to prevent an uneven pressure on the silica rod (*see* Fig. 1). A constant-pressure gas quench did not give a relationship that was close enough to actual welding conditions, since Rosenthal[12] and others[4, 9] have shown that the cooling rate of a weld on an 'infinite' plate obeys the relationship

$$R \propto (t - t_0)^2,$$

where R = rate of cooling at temperature t
t_0 = initial or background temperature of plate.

The gas was therefore passed into a cylinder of known volume at a known pressure. This volume of gas was shut off from the source before being passed through the dilatometer. By regulation of the cylinder volume, gas pressure, and size of inlet nozzle to the dilatometer, cooling rates were produced in the specimen showing good agreement with weld cooling rates.

For the quenching apparatus two pressure cylinders, having volumes of 1 and 2¼ cu. ft., and one low-pressure tank, having a volume of 4 cu. ft., were employed. The tank and cylinders were connected to each other (to a pressure/vacuum gauge) and to the gas supply and outlet by means of various cocks, so that any combination of the three volumes could be obtained at pressures up to 30 lb./sq. in. A small flow of gas was used during heating, to prevent oxidation of the dilatometer specimen.

To obtain the high rate of heating required to simulate the welding thermal cycle, an electronic H.F. induction heater having a rating of 1 kW. was used; the heating coil of the machine is shown in

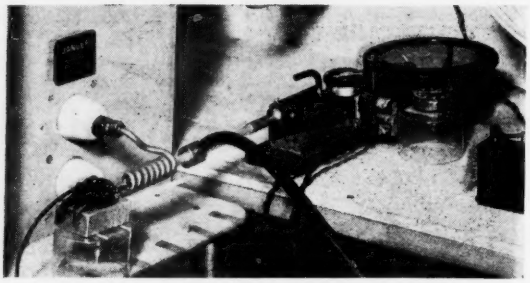

Fig. 2—Dilatometer, heating coil, and instruments

Fig. 2. This method of heating allowed peak temperatures of over 1200° C.* to be obtained in the specimen, with time intervals above Ac_3 of 7–8 sec., the total heating time being about 10 sec.

Difficulty was experienced with temperature measurement, owing to induced currents in the thermocouple leads. These currents would have caused damage to the temperature indicator, so a filter was inserted in the leads to the indicator. This filter comprised three tuned circuits to remove the H.F. currents at the three major frequencies, and has been described elsewhere.[13]

INITIAL TESTS TO DETERMINE HEATING AND COOLING CYCLES

Tests to reproduce thermal cycles similar to those occurring in the heat-affected zones of the large and small welds previously described were made using different combinations of gas pressure, cylinder volume, and gas inlet nozzle area. Some typical curves are shown in Fig. 3, where the cooling curve associated with the small weld is being matched.

* To establish the peak temperature to which the specimens should be heated, the position of cold cracks in relation to their distance from the fusion line was examined. The cracks occurred in the region of the heat-affected zone, which had been subjected to a peak temperature in the range 1100–1400° C.

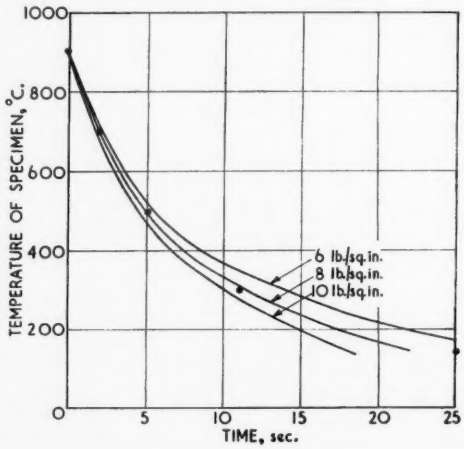

Fig. 3—Relationship between cooling cycle and initia gas pressure for 1-in. long dilatometric specimen quenched from 1220° C. Superimposed points indicate weld cooling cycle (rate 2)

Points from the weld cooling curve to be imitated are also shown, and a comparison of these points with the various curves indicates how an initial gas pressure of 7½ lb./sq. in. was chosen.

Some difficulty was experienced in matching the cooling rates of the large fillet welds. Owing to the large number of welds there was inevitably some variation in heat input, with consequent difference in cooling rates. To standardize the cooling conditions for all the dilatation tests, the higher cooling rates in the range were imitated. As there were relatively few welds having the lower cooling rates (larger heat inputs), this condition matched the majority of the test welds.

Experiments were made to determine the temperature distribution along the specimen during quenching. The results showed that the temperature at the end near the gas outlet did not differ greatly from the temperature at the centre of the specimen over the whole temperature range. There was, however, a greater difference between the temperature at the end near the gas inlet and the temperature at the centre of the specimen. This temperature difference affects only the determination of the onset of transformation, and has little effect on the accuracy with which the temperature for the finish of transformation is determined. The temperature lag between the gas outlet and the centre of the specimen affects the

Table I

SUMMARY OF PREVIOUS TEST RESULTS ON THE SERIES OF STEELS

Steel No.	Average Plate Hardness,* D.P.N.	Weld Heat-Affected Zones				Mechanical Properties*			
		Large Fillet		Small Fillet		0·3% Proof Stress, tons/sq. in.		U.T.S., tons/sq. in.	
		Average Peak Hardness, D.P.N.	Cracking, % leg length	Average Peak Hardness, D.P.N.	Cracking, % leg length				
	(*a*)					(*b*)	(*c*)	(*b*)	(*c*)
1	174	274	Nil	326	Nil	21·5	21·0	35·0	33·0
2	194	361	Nil	399	17	26·6	23·5	43·3	41·0
3	222	391	28	419	51	33·1	27·5	52·5	46·1
4	188	301	Nil	376	0·3	24·9	19·2	39·2	34·5
5	216	379	Nil	408	47	28·5	22·2	45·2	39·0
6	232	383	25	408	43	34·8	30·8	52·6	49·3
7	200	343	Nil	388	4	28·0	22·5	42·5	38·4
8	219	386	21	419	59	31·3	29·5	49·5	46·6
10	201	337	Nil	380	Nil	29·2	19·0	45·4	35·8
11	219	388	5	410	32	34·0	25·5	51·0	41·8
12	255	406	31	420	56	35·8	33·5	57·2	53·2
13	186	346	Nil	387	0·2	29·8	21·0	44·5	36·8
14	222	388	14	402	40	32·8	25·0	50·0	40·2
15	299	410	32	427	60	44·5	41·0	62·7	62·0
16	211	354	0·2	401	8	31·1	19·0	44·5	38·5
17	254	399	26	416	55	38·0	36·5	56·5	54·5
18	294	412	37	423	64	45·0	41·5	62·7	60·8
19	192	351	Nil	392	15	33·0	21·5	48·4	38·4
20	197	362	Nil	401	36	33·3	28·0	50·3	45·6
21	266	406	25	411	55	42·5	41·5	62·3	59·6
22	235	347	1	394	22	32·0	25·0	52·4	43·0
23	291	401	54	413	71	38·0	39·0	55·0	57·0
24	328	420	48	433	69	50·0	47·8	69·4	69·4
25	276	398	27	407	45	38·0	34·8	57·2	53·0
26	302	415	57	415	60	50·0	44·4	67·0	66·6
27	329	412	63	422	77	53·5	51·5	71·4	70·0
28	216	346	0·5	381	23	29·0	25·5	47·0	44·0
29	224	372	19	384	17	32·0	27·5	49·2	44·5
30	252	382	37	402	42	35·8	29·8	54·8	48·5
31	272	400	33	405	57	38·0	35·8	57·0	53·5
33	245	387	44	433	70	32·5	25·8	50·8	43·5
34	184	333	Nil	367	3	23·2	18·4	41·2	36·0
35	227	390	2	413	34	33·5	24·5	50·8	42·0
36	261	404	35	424	58	36·0	28·5	54·2	46·5
X	200	285†	Nil†			30·2 (*a*)		39·6 (*a*)	

* (*a*) Normalized in ¼-in. thick plate
(*b*) Normalized in ¼-in. square section, equivalent to ¼-in. thick plate
(*c*) Normalized in ¼-in. square section between ¼-in. thick plates, equivalent to 1¼-in. thick plate

† Results for a more severe test

determination of the temperature for complete transformation. This temperature difference is not great in the range (below 400° C.) in which the steels being tested should finish transforming. Correction curves for both high and low cooling rates have been plotted, and the greatest temperature difference observed was 23° C. at 400° C.

DILATATION TESTS

Using Low Cooling Rate, Simulating Conditions in Large Fillet Welds

In these experiments all the steels given in Tables I and II were tested. Some could have been left untested, since they showed severe hard-zone cracking in the weld test, but by testing the whole series additional useful data were obtained on the effect of various alloying elements on the transformation characteristics.

The dilatation/temperature and time/temperature relationships were plotted for each test. For the first few steels, duplicate experiments were made; good agreement was obtained between them, and subsequently only one test was made on each steel. The differences observed between duplicate tests on steels 1, 2, and 3 were 5, 0, and 0° C. respectively for start of transformation, and 10, 10, and 5° C. respectively for finish of transformation.

The dilatation/temperature and time/temperature relationships observed for one of the steels are shown in Fig. 4. The temperatures observed for the start, 50% completion, and finish of transformation are shown, together with the method of obtaining the temperature for 50% transformation.*

The temperatures for completion of transformation during cooling, for all the steels, were corrected

* These values are liable to some error, as it is not possible to correct them for temperature gradient along the specimen.

Table II

CAST ANALYSES OF STEELS

Steel No.	C, %	Si, %	S, %	P, %	Mn, %	Ni, %	Cr, %	Mo, %	Cu, %	B, %
1	0·14	0·18	0·029	0·036	0·73	0·48	0·24	0·22	...	...
2	0·16	0·18	0·025	0·038	1·13	0·50	0·25	0·24	...	...
3	0·15	0·21	0·030	0·044	1·52	0·51	0·25	0·24	...	...
4	0·15	0·17	0·029	0·035	0·78	1·01	0·25	0·22	...	...
5	0·16	0·22	0·025	0·035	1·15	1·00	0·25	0·22	...	...
6	0·13	0·20	0·025	0·037	1·53	1·01	0·25	0·22	...	...
7	0·16	0·17	0·027	0·037	0·74	1·51	0·24	0·22	...	...
8	0·16	0·21	0·026	0·036	1·11	1·55	0·24	0·22	...	...
10	0·15	0·23	0·027	0·032	0·79	0·50	0·68	0·22	...	...
11	0·155	0·21	0·034	0·023	1·22	0·55	0·65	0·26	...	...
12	0·16	0·19	0·042	0·021	1·58	0·57	0·66	0·245	...	...
13	0·145	0·15	0·028	0·024	0·71	1·06	0·60	0·26	...	...
14	0·17	0·22	0·028	0·024	1·00	1·05	0·645	0·265	...	...
15	0·15	0·21	0·043	0·021	1·71	1·07	0·66	0·24	...	...
16	0·155	0·15	0·024	0·024	0·64	1·57	0·56	0·245	...	...
17	0·155	0·20	0·027	0·025	1·26	1·52	0·66	0·25	...	...
18	0·16	0·18	0·043	0·024	1·70	1·53	0·62	0·23	...	...
19	0·155	0·17	0·032	0·024	0·74	0·57	1·03	0·245	...	...
20	0·135	0·18	0·043	0·021	1·00	0·51	1·00	0·235	...	...
21	0·135	0·18	0·043	0·024	1·64	0·55	0·89	0·25	...	...
22	0·13	0·18	0·035	0·031	0·80	1·03	1·01	0·25	...	...
23	0·13	0·18	0·036	0·034	1·25	1·02	0·99	0·25	...	...
24	0·15	0·21	0·035	0·034	1·70	1·03	1·03	0·25	...	...
25	0·17	0·16	0·032	0·029	0·79	1·59	1·01	0·25	...	...
26	0·15	0·21	0·032	0·029	1·26	1·55	1·00	0·26	...	...
27	0·13	0·23	0·033	0·034	1·64	1·50	1·03	0·23	...	...
28	0·13	0·19	0·035	0·035	0·86	0·94	0·23	0·21	0·94	...
29	0·14	0·21	0·035	0·032	0·83	1·44	0·22	0·25	1·12	...
30	0·15	0·20	0·033	0·026	0·87	1·02	0·58	0·25	1·13	...
31	0·14	0·19	0·033	0·028	0·84	1·49	0·63	0·25	1·12	...
33	0·13	0·19	0·023	0·040	1·52	0·07	0·17	0·26	...	...
34	0·16	0·21	0·022	0·040	0·83	0·07	0·52	0·25	...	...
35	0·14	0·18	0·027	0·039	1·23	0·09	0·56	0·25	...	...
36	0·13	0·17	0·021	0·041	1·42	0·09	0·56	0·25	...	...
X	0·12	0·28	0·033	0·024	0·50	...	...	0·40	...	0·0033 (sol.) 0·0001 (insol.)

for the temperature gradient. When these temperatures are related to the severity of hard-zone cracking observed in the corresponding weld tests, a significant relationship is observed. This is illustrated in Fig. 5*a*, in which the temperature for completion of transformation is plotted against severity of hard-zone cracking. There is no linear relationship between them, but there is an abrupt change in the relationship at 290° C. The steels that finished transforming below this temperature contained hard-zone cracks in the weld test.

Temperatures for 50% transformation and the corresponding severity of hard-zone cracking are related in Fig. 5*b*. In this instance there is a linear increase of crack severity with decrease in temperature, but with considerable scatter, and there is no abrupt change at any temperature.

For the Mn–Ni–Cr–Mo steels 1–27, the Mn–Ni–Cr–Mo–Cu steels 28–31, and the Mn–Cr–Mo steels 33–36, a decrease in cooling rate was apparent on the temperature/time curve of the dilatation tests during the transformation of austenite. With the B–Mo steel *X* the effect was more marked, there being a rise in temperature of 10° C. from 530° to 540° C. during transformation.

Using High Cooling Rate, Simulating Conditions in Small Fillet Welds

The steels chosen for this series of tests were those (*see* Tables I and II) near the borderline of hard-zone cracking in the test with the small fillet weld (high cooling rate).

One test was made on each steel, and the dilatation/temperature and time/temperature relationships for steel 2 are shown in Fig. 6. The severity of hard-zone cracking in the weld test and the temperatures for completion and 50% transformation are related in Figs. 7*a* and *b*, respectively, the temperature for finish of transformation being corrected for temperature gradient.

The temperature of 290° C. for the finish of transformation during cooling again proved to be critical. Steels in which transformation was complete above this temperature were free from cracking when welded with the small fillet weld, whereas with steels in which transformation continued below 290° C., hard-zone

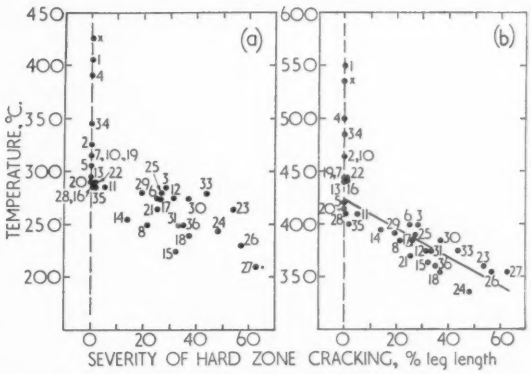

Fig. 5—Relationship between transformation temperature during continuous cooling and the extent of cracking in weld test (rate 1): (*a*) For completion of transformation; (*b*) for 50% transformation

cracks were present in the weld test. These results are in agreement with the previous tests, the temperature of 290° C. being critical in both instances.

TRANSFORMATION OCCURRING AT ROOM TEMPERATURE SUBSEQUENT TO THE THERMAL CYCLE

In the dilatation tests described, there was an indication that some transformation was occurring in the rapid-response dilatometer after the specimen had reached room temperature. However, the dilatometer was so constructed that it could not measure these changes with accuracy. The transformation produced a slight increase in length of the specimen soon after it had reached room temperature. This effect is consistent with the transformation of small amounts of retained austenite under isothermal conditions.

The work of Mallet and Rieppel[8] indicated that, provided no austenite is retained in the heat-affected zone, hard-zone cracking will be absent when alloy steel is arc-welded, even if hydrogen is present. Following these results and the effects shown in the rapid dilatation tests, it was decided to investigate the effect further, with a view to observing any relationship between incidence of hard-zone cracking

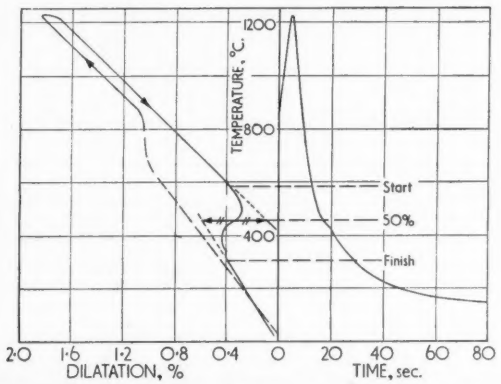

Fig. 4—Dilatation and cooling curves for steel 2 (rate 1)

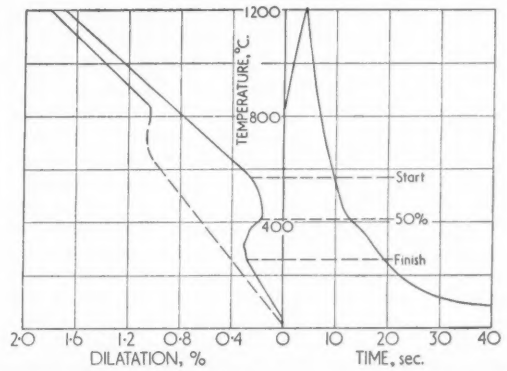

Fig. 6—Dilatation and cooling curves for steel 2 (rate 2)

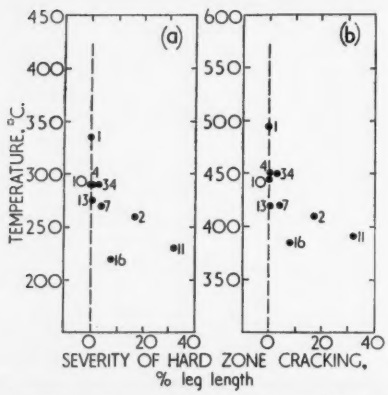

Fig. 7—Relationship between transformation temperature during cooling and the extent of cracking in weld test (rate 2): (*a*) For completion of transformation; (*b*) for 50% transformation

and room-temperature dilatation in some of the experimental steels.

To study the room-temperature dilatation a dilatometer was constructed which was comparatively unaffected by change of ambient temperature. Eight steels which had shown considerable difference in severity of hard-zone cracking (0–28%) in the weld test were selected. The steel specimens were transferred from the high-speed dilatometer to the isothermal dilatometer as soon as they reached room temperature after the thermal cycle (rate 1, simulating large weld). Readings of the dial gauge were taken periodically, and it was found that most of the expansion occurred during the first 2 hr., no change in length being observed after 2 days up to a period of 14 days. The results are given in Table III, from which it can be seen that there is no relationship between room-temperature dilatation and severity of hard-zone cracking in the corresponding weld test. The extensions observed were probably due to the transformation of small amounts of retained austenite, as heat-affected zones of steels of this type are known to contain substantial amounts of retained austenite some days after welding. In the heat-affected zone of a similar low-alloy steel, Tremlett[14] found up to 5% of retained austenite, using an X-ray method.

HARDNESS OF DILATATION SPECIMENS AFTER SIMULATING WELDING CONDITIONS

After testing, the dilatation specimens were cut longitudinally and transversely and the exposed faces were micro-polished. Hardness impressions were made on each specimen, using a 10-kg. load and a diamond pyramid indenter. Ten impressions were made at intervals of $\frac{1}{10}$ in. along the longitudinal section, and three impressions were made about $\frac{1}{8}$ in. apart on the semi-circular transverse section. Average values were taken for impressions made over a distance of $\frac{1}{4}$ in. on either side of the centre of each specimen, and were compared with the hardness values observed in the heat-affected zones of the welds on these steels.

In general, there was good agreement between the hardness values observed on the welded specimens and on the dilatation test-pieces when simulating the thermal conditions occurring in the large fillet weld. It should be remembered, however, that the thermal conditions produced in the dilatation specimens were constant, whereas some of the welding tests were made using rather lower cooling rates, as mentioned on p. 19. There was a slight tendency towards lower hardness values in the dilatation test-pieces. In the tests simulating the thermal conditions of the small fillet weld there was fair agreement between the two sets of hardness values, even lower hardness values being produced in this instance with the synthetic thermal cycle.

The reason for rather lower values of hardness obtaining in the dilatation specimens may be the absence of hydrogen. It has been suggested[14] that hydrogen delays transformation, and if this is so it may increase the hardness values. Some of the differences between the two sets of hardness values may have been due to the fact that the values from the weld tests were not a true average for a whole length of weld, since their accuracy depends upon a constant electrode travel speed, which seldom occurs during manual welding. There was some variation in hardness along the longitudinal sections of the dilatation specimens from the lower-alloy steels. The range of hardness variation was up to 43 D.P.N. for the lower-alloy steels and as low as 10 D.P.N. for the higher-alloy steels. The greater variation in the hardness of the lower-alloy steels is because the

Table III

ISOTHERMAL DILATATION AT ROOM TEMPERATURE AFTER SIMULATING WELDING CONDITIONS

Steel No.	Severity of Hard-Zone Cracking (Large Weld), % leg length	Transformation at 16–22° C. 2 days after Thermal Treatment, Rate 1	
		Volume Change, %	Calculated Amount of Retained Austenite Transformed, %
3	28	0·045	1·0
4	Nil	0·018	0·4
5	Nil	0·017	0·4
6	25	0·017	0·4
7	Nil	0·022	0·4
8	21	0·024	0·5
10	Nil	0·022	0·5
11	5	0·018	0·4

Table IV

TRANSFORMATION TEMPERATURE AND CRACKING DATA

Steel No.	Temperature for Completion of Austenite Transformation During Cooling (Rate 1), ° C.	Severity of Heat-Affected Zone Cracking in Weld Test (Large Weld), % leg length
19	315	Nil
5	305	Nil
22	290	1
16	285	<1
28	285	<1
11	285	5
29	280	19

Table V

WELD HEAT-AFFECTED-ZONE HARDNESS AND CRACKING DATA

Steel No.	Average Peak Hardness in Heat-Affected Zone of Weld Test (Large Weld), D.P.N.	Severity of Heat-Affected Zone Cracking in Weld Test (Large Weld), % leg length
28	346	<1
22	347	1
19	351	Nil
16	354	<1
29	372	19
5	379	Nil
11	388	5

transformation of austenite in these steels takes place over a wide range of temperature, yielding both martensite and higher-temperature transformation products. A small change in cooling rate can therefore produce either a mainly martensitic structure or one chiefly composed of higher-temperature transformation products.

The temperature variation that existed along the length of the specimen was reflected in the hardness values, and was amplified in the case of steels giving both transformation products. The higher-alloy steels of the series are normally fully martensitic with the cooling rate used, and consequently the temperature variation along the specimen had little or no effect on the resulting hardness. In addition, these steels showed a tendency to soften in the heat-affected zone, which indicated some retention of austenite after cooling.

DISCUSSION

This investigation has shown the importance of the temperature for completion of austenite transformation during cooling, in relation to the formation of hard-zone cracks when welding low-alloy steels. This relationship is more precise than the previous method used for determining the weldability of steel, *i.e.*, the suggested safe upper limit of hardness in the heat-affected zone.[1, 2] A comparison of the two methods is shown in Tables IV and V, for seven steels on the border-line of cracking in the weld test.

In Table IV the steels are in order of decreasing temperature for completion of transformation, whereas in Table V they are in order of increasing hardness produced in the heat-affected zones of the weld tests. The correlation between transformation temperature and incidence of hard-zone cracks is good, whereas

Table VI

DILATOMETER SPECIMEN HARDNESS AND CRACKING DATA

Steel No.	Average Hardness of Heat-Treated Specimen (Rate 1), D.P.N.	Severity of Heat-Affected-Zone Cracking in Weld Test (Large Weld), % leg length
16	347	<1
22	349	1
19	355	Nil
5	361	Nil
28	365	<1
11	385	5
29	392	19

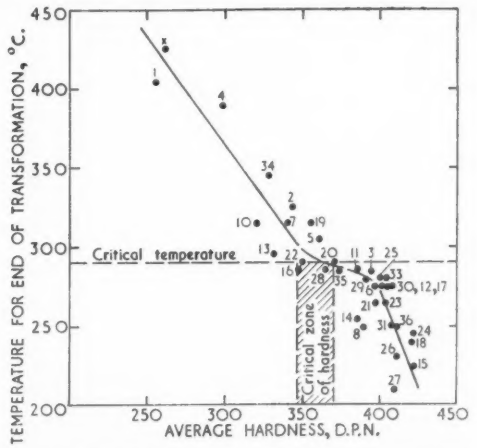

Fig. 8—Relationship between hardness and temperature for completion of transformation during cooling (rate 1)

there is little agreement between hardness and cracking. This poor agreement may be partly due to the fact that the hardness values from the weld tests are not a true average (*see* p. 22); there is better agreement when hardness values of the corresponding dilatation specimens are used (*see* Table VI).

There is a general increase in the average hardness of the dilatation specimens as the temperature for completion of transformation decreases. These two factors are related in Fig. 8; there is some scatter and a departure from linearity around the critical temperature (290° C.). The non-linearity is probably caused by a sudden increase in the amount of martensitic product without appreciable change in the temperature for completion of transformation. Figure 8 also gives the critical temperature of transformation and critical zone of hardness for the threshold of hard-zone cracking. The presence of a zone of critical hardness related to the incidence of cracking, instead of an abrupt demarcation, could also be due to the sudden increase in amount of martensitic product formed. This may account for the difficulty previously experienced in defining a safe upper limit of hardness in the heat-affected zone of welds in alloy steel.

The effect of the individual alloying elements manganese, nickel, and chromium on the temperature for completion of transformation, using the low cooling rate, varies considerably with each element. In Fig. 9 the alloy content is plotted against transformation temperature for these three elements. The addition of manganese produces a marked reduction in the transformation temperature in all cases. Increase in nickel content also decreases this temperature, but the effect is only marked in the high-nickel range (1·0–1·5%). Additions of chromium decrease the transformation temperature, but the effect of this element is only slight in the high-chromium range (0·6–1·0%).

These results indicate that nickel contents up to 1·0% should not greatly affect the weldability of steels of this type, and that chromium contents of 0·6–1·0% should also have little effect. However,

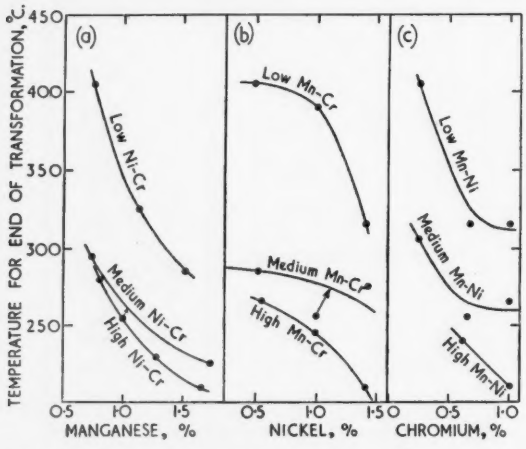

Fig. 9—Effect of variations in the content of (*a*) manganese, (*b*) nickel, and (*c*) chromium on the temperature for completion of transformation (rate 1)

additions of manganese in all amounts should adversely affect weldability. These indications are in agreement with the results of previous work[3] on the metal-arc welding of these steels.

When testing the boron–molybdenum steel *X*, an increase in temperature of 10° C. was produced in the dilatation specimen during transformation, indicating that the higher-temperature transformation proceeds more rapidly than in the other steels examined, since none of these showed the same effect. In addition, no martensitic transformation occurred in steel *X*. The boron-containing steel gave such a rapid transformation in the upper temperature range that all transformation was completed before the temperature fell sufficiently to produce a martensitic product. This is consistent with the excellent weldability observed with this type of steel.

CONCLUSIONS

For a given set of welding conditions, the presence of cracks in the hard zone for a series of metal-arc welded alloy steels has been related to the temperature for completion of austenite transformation during cooling. When transformation is completed above 290° C. cracking is absent, but when transformation continues below 290° C. cracks occur.

This relationship explains the importance of rate of cooling at 300° C.[4,11] in relation to hard-zone cracking in alloy steels. When welding a particular steel with a rutile electrode, a given cooling cycle may produce hard-zone cracks with completion of transformation below 290° C. By maintaining the same cooling rate at high temperatures and retarding the cooling rate in the region of 300° C., the transformation will be completed above 290° C., and hard-zone cracks should be absent.

FUTURE WORK

These results have shown the need for a fuller investigation of the transformation characteristics of alloy steels in relation to their susceptibility to hard-zone cracking.

The investigation has dealt with the weldability of various steels under a standard set of conditions, as the results apply mainly to one electrode and to one type of welded joint. It has been shown[4, 11] that both the 'thermal severity' (depending on plate thickness and joint geometry) of the joint being welded and the fillet size of the weld affect the severity of cracking. Different types of electrode also affect the severity of cracking, this effect having been reported elsewhere.[10, 15, 16]

The second stage of this investigation will therefore take into account these two factors, and will relate the tendency for hard-zone cracking to the transformation characteristics of a particular steel welded with various fillet sizes and types of electrode. For this purpose, continuous-cooling time/temperature/transformation diagrams will be produced for the steel, by using a more sensitive dilatometer with a minimum temperature gradient along the specimen. In addition, it is proposed to investigate the effect on the time / temperature / transformation diagram of hydrogen introduced into the dilatometer specimen.

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The Cleavage Strength of Polycrystals

By

N. J. Petch, B.Sc., B.Met., Ph.D.

SYNOPSIS

Using mild steel, ingot iron, and spectrographic iron, it is found that the cleavage strength σ_c is related to the grain size l by

$$\sigma_c = \sigma_0 + kl^{-\frac{1}{2}}.$$

This can be explained if the Griffith cracks can be identified with glide planes on which dislocation movement has been blocked by the grain boundaries.

According to this theory, the cleavage strength of the polycrystals is controlled by the theoretical cleavage strength in the grain-boundary region, which opens up the possibility of subtle composition effects in this special region, by the grain size, which determines the stress-concentration factor, and by σ_0. The plastic strain at fracture is greater when the grains are finer and the strain-hardening rate is lower. 744

It is well known that coarse-grained steels are more prone to brittle fracture than fine-grained ones, and the present paper describes a detailed examination of this feature, undertaken in the hope that an understanding of it might throw a light on the whole subject of brittle fracture.

Notched specimens of various forms are often used in this type of investigation, but the occurrence of brittle fracture in such cases depends upon both the yield stress and the brittle, or cleavage, strength.[1] To separate these two properties, the tensile fracture of unnotched specimens in liquid nitrogen was used in the present work, and the cleavage strength was obtained as the fracture stress. The variation of this cleavage strength with ferritic grain size was studied.

EXPERIMENTAL DETAILS

Mild steel, ingot iron, and spectrographic iron were used, and a few measurements were also made on the mild steel after decarburization. The compositions of the metals were as follows:

	Ingot Iron	Spectrographic Iron	Mild Steel
C, %	0·036	0·07	0·155
Si, %	<0·005	<0·005	0·10
Mn, %	0·10	0·005	0·59
P, %	0·007	0·005	0·028
S, %	0·020	0·006	0·033
Ni, %	0·07	0·01	0·18
Cr, %	...	...	0·11
Mo, %	...	...	0·025
O, %	0·042	0·012	0·018
N, %	0·003	0·008	0·004

The specimens ($\frac{1}{4}$-in. dia. ends) were prepared with care; all machining marks were removed from the gauge length and the necks by polishing with 000 emery paper. The machining stresses were relieved by the subsequent heat treatment *in vacuo* that was used to establish the required grain sizes, which ranged from single crystals to 8000 grains/sq. mm. Almost all these sizes were obtained by heat treatment at temperatures up to 1050° C. for times up to 24 hr., followed by cooling at various rates. For the fastest rate, the specimens were sealed in evacuated thin-walled silica tubes, and were air-cooled. Results were also obtained from other specimens treated at temperatures up to 1350° C., but, with one exception, the fractures were found to be intercrystalline instead of cleavage, so that these fracture stresses had to be discarded. The single crystals and a few coarse-grained specimens were obtained by straining and annealing the decarburized mild steel.

To promote true axial loading during the mechanical testing, the specimens were screwed directly into polished $\frac{1}{2}$-in. dia. ball-bearings resting in polished, hardened tool-steel seatings. A testing machine was used in which the load was measured by the longitudinal elastic deformation of a bar, and this deformation was followed by a mirror extensometer that was illuminated by a beam of light. By this means, a direct photographic record of the stress/strain curve could be obtained.

To obtain satisfactory reproducibility, it was found that 6–12 separate counts of grain size were desirable on each specimen. Since the specimen surface was a random section through the grains, the figure derived for the grain diameter was in fact proportional to the true diameter.

RESULTS

Various amounts of plastic deformation before fracture were observed, depending upon the grain size, and some allowance for this was necessary, since the cleavage strength is altered by plastic strain. To make the results directly comparable at the various grain sizes, a correction to zero deformation was carried out using the pre-strain/cleavage-strength curves determined by McAdam, Geil, and Mebs[2] for an ingot iron and a low-carbon steel. These were obtained by deformation at room temperature, followed by fracturing at − 188° C. This correction is not perfect; low-temperature strain produces more strain hardening than the same amount of room-temperature strain, so that there is probably an underestimate. However, the correction was negligible for about half the results and was small for many of the others, although it did reach 25 tons/sq. in. for the few specimens with a reduction in area of about 35%.

Some allowance had also to be made for the non-uniform stress distribution in the cross section when there was necking. For the few cases that occurred, the greatest stress was calculated using Bridgman's

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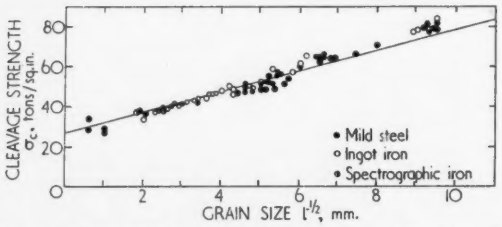

Fig. 1—Relationship between cleavage strength and grain diameter

analysis.[3] The corrections were small and were in the opposite direction to the plastic-strain correction.

The cleavage-strength/grain-size results are shown in Fig. 1. Because of overlapping, this diagram does not include all the experimental points. There is a large change in cleavage strength (25–85 tons/sq. in.) over the range of grain sizes examined, and the relationship between the cleavage strength σ_c and the grain diameter l corresponds closely to the form

$$\sigma_c = \sigma_0 + kl^{-\frac{1}{2}}$$

where σ_0 and k are constants.

In drawing the line shown in Fig. 1, greatest weight was given to the results up to $l^{-\frac{1}{2}} = 5$, because the plastic-strain corrections were zero or very small. At larger $l^{-\frac{1}{2}}$ values (*i.e.*, smaller grain sizes), the cleavage strengths lie a little above this line, but this is consistent with the greater plastic strains involved in these specimens and the probable under-estimate of the strain correction.

THEORY OF THE CLEAVAGE-STRENGTH/GRAIN-SIZE RELATIONSHIP

The basic problem in fracture is to understand the physical nature of the imperfections (the Griffith cracks[4]) that account for the difference between the theoretical and the observed strengths.

Actual cracks of the Griffith form in a metal would close up in the absence of external stress unless they were prevented from doing so by included atoms, so it is possible that the Griffith cracks can be identified with precipitates in the form of very flat plates. Cracks could then develop under stress owing to a low adhesion between the precipitate and matrix and to differences in their elastic and plastic properties.

There are probably cases, particularly of intercrystalline fracture, in which precipitates form the effective Griffith cracks, and the author was first attracted to the possibility that this might be the case with the present cleavage fractures. The Griffith expression for the cleavage strength ($\sigma_c = \sqrt{(2ES/\pi c)}$, where E, S, and $2c$ are the Young's Modulus, surface energy, and crack size respectively) would then require a specific relationship between precipitate size and grain size to account for the observed variation of cleavage strength. However, a detailed examination of the cleavage strength of recrystallized zinc by Zein and the present author[5] also gives $\sigma_c = \sigma_0 + kl^{-\frac{1}{2}}$ (σ_0 is very small), and it would be surprising if the same form of precipitate-size/grain-size relationship existed in both cases. Some more general theory would be more acceptable.

Such a general theory can be supplied if the Griffith cracks can be identified with glide planes on which dislocation movement has been held up by blockage at a grain boundary. The tensile stresses at the head of such an array of dislocations can be very high, and the theoretical cleavage strength may be attained and fracture initiated. It should be possible to calculate the cleavage-strength/grain-size relationship that would result from this mechanism.

Zener,[6] who first dealt with slip planes as stress concentrators, has compared the concentration due to relaxation of the shear stress on a slip plane with that due to a crack. In a recent paper, Eshelby, Frank, and Nabarro[7] have calculated the positions taken up by the dislocations in an array of like dislocations that is pressed against an obstacle and the shear stresses that result. Koehler[8] has used these dislocation positions to calculate the tensile stresses. In the present instance, this calculation will be extended to establish the cleavage-strength/grain-size relationship.

Koehler examined an array of n like dislocations pressed against an obstacle by a shear stress τ. Summation of the stresses due to the individual dislocations showed that high tensile stresses are produced in the region at the head of the array that are of the form

$$\sigma = \alpha n\tau \qquad (1)$$

where σ is the stress and α is a constant.

To extend this result into a cleavage-strength/grain-size relationship, the connection between n and the grain size is required.

The dislocations initially present within the crystal can probably begin to move at small stresses, lower than the conventional yield point, but they cannot pass beyond the confines of the grain boundary. On the glide planes that contain a Frank-Read[9] source, there will be dislocation multiplication, and this will continue until the accumulation of the dislocations on the glide plane and the interaction between the dislocations within the accumulation stop the multiplication for that particular applied stress. There will then be an array of n positive dislocations pressing against the grain boundary at one end of the glide plane and n negative dislocations pressing against it at the other end of the glide plane; the largest value of n will arise in grains with a source at the centre. Since the interaction between the positive and negative dislocations will be confined mainly to the centre of the grain, the two parts of the array can be treated separately, to a first approximation. The maximum value of n under any stress τ can then be calculated from the condition that the length of an array of

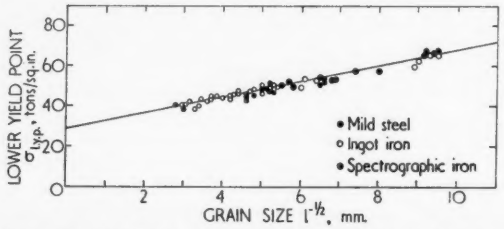

Fig. 2—Relationship between lower yield point and grain diameter

n like dislocations under this stress must be equal to half the grain diameter.

The length L of an array of like dislocations as calculated by Eshelby, Frank, and Nabarro is given by $L = 2nA/\tau$, where $A = Gb/2\pi(1 - \nu)$ and G, b, and ν are the rigidity modulus, Burgers vector, and Poisson's ratio respectively.

When there is dislocation saturation for τ, L can be identified with the semi-diameter $l/2$ of the grain.*

Hence, $$l = \frac{4nA}{\tau} \quad \text{and} \quad n = \frac{l\tau}{4A}.$$

Substituting this value of n in equation (1) gives

$$\sigma = \frac{\alpha l \tau^2}{4A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In the array that has been considered so far, it has been assumed that the dislocations are free to move with the applied shear stress, within the limitation of their own interaction. In real crystals, however, there will also be an internal stress field due to dislocations outside the array. Since the glide planes of interest as stress concentrators have the most densely packed dislocations, the dislocation spacing on the neighbouring planes must be wider. These neighbours will consequently introduce a stress tending to open up the densest plane to their own dislocation spacing and this stress will oppose the applied shear stress. The dislocation spacing normal to the glide plane will not be affected by the operation of the Frank-Read source, and increase in the value of τ will decrease the spacing on both the densest planes and their neighbours, so a reasonable approximation is that the internal stress can be represented by an average shear stress τ_0 in opposition to τ and independent of it.

Then, from equation (2),

$$\sigma = \frac{\alpha}{4A}(\tau - \tau_0)^2 l.$$

In terms of the tensile stresses σ^* and σ_0 corresponding to τ and τ_0,

$$\sigma \propto (\sigma^* - \sigma_0)^2 l.$$

When σ reaches the theoretical cleavage strength $\sigma_{t.c.s.}$,

$$\sigma^* = \sigma_c.$$

$$\sigma_{t.c.s.} \propto (\sigma_c - \sigma_0)^2 l.$$

If this is rearranged, with $\sigma_{t.c.s.}$ constant,

$$\sigma_c = \sigma_0 + kl^{-\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where k is a constant.

Thus, provided that the theoretical cleavage strength at the grain boundary is not appreciably affected by dislocation multiplication below the yield point, equation (3) gives the cleavage-strength/grain-size relationship for zero plastic deformation. This agrees with the observed relationship.

THE YIELD POINTS

The dependence of the lower yield point on the grain size in these experiments (*see* Fig. 2) was of the form $\sigma_{l.y.p.} = \sigma_0 + k^* l^{-\frac{1}{2}}$, and the results for the different materials lay on the same line. This is in agreement with Hall's room-temperature measurements.[10] The upper yield point lay above the lower for fine grains, but they merged at about $l^{-\frac{1}{2}} = 5$.

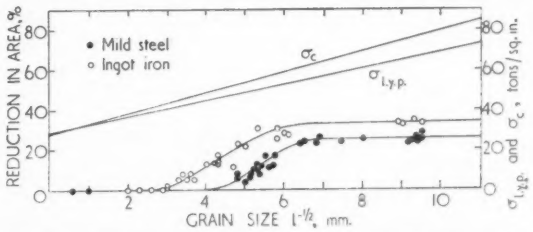

Fig. 3—Experimental curves for the dependence of the cleavage strength, lower yield point, and reduction in area on the grain diameter

The cleavage strength and lower yield point are plotted together in Fig. 3 without the experimental points. It will be seen that σ_0 is common.

If the ideas of the previous section are correct, this similarity between the cleavage-strength/grain-size and the yield-point/grain-size relationships is to be expected. The lower yield point, which represents the propagation of a Lüder's line, and probably also the upper yield point[10,11] are, like cleavage, concerned with the stress concentration produced by a blocked glide plane. The yield point involves the shear stresses, whereas cleavage involves the normal stresses.

INFLUENCE OF CARBON CONTENT

According to the present theory, the cleavage strength of low-carbon steels, in which ferrite predominates in the microstructure, is determined by the fracture of one ferrite grain under the influence of dislocations in another ferrite grain. Ferrite alone is involved, and the cleavage strength, corrected for plastic deformation, should be nearly independent of the pearlite content. This is borne out by Fig. 1. The independence of carbon content shown by the yield point (*see* Fig. 2) is of essentially similar origin.

The presence of pearlite, however, increases the strain-hardening rate, and so it should reduce the amount of plastic strain required to raise the stress from the yield point to the cleavage strength. In agreement with this, the reduction in area (*see* Fig. 3) was found to be greater for the ingot iron than for the mild steel.

As would be expected, Fig. 3 also shows that the reduction in area increases for the finer grain sizes, owing to the increasing separation of σ_c and $\sigma_{l.y.p.}$. The reduction in area does not increase indefinitely, but becomes constant. The separation of σ_c and $\sigma_{l.y.p.}$, which refer to zero plastic strain, does not fully indicate what the reduction in area will be; the rates of increase of cleavage strength and of yield stress with strain and the influence of grain size on these rates are also involved.

CONCLUSIONS

The present work indicates that the cleavage strength of polycrystals is controlled by the theoretical cleavage strength in the vicinity of the grain boundaries, by σ_0, and by the grain size. The latter determines the magnitude of the stress-concentration

*After yielding, arrays of dislocations of like sign can probably be produced that extend right across a grain. This does not alter equation (3).

factor. Since a property of the grain-boundary region is involved, subtle effects of composition are possible owing to the segregation of solute atoms to this special region and to the effect of other solute atoms on this segregation.

The amount of plastic strain at fracture, which depends partly on the separation of the yield point and the cleavage strength, will increase with finer grain sizes (eventually becoming constant) and lower strain-hardening rates. Composition effects at the grain boundary that affect the cleavage strength may also affect the yield point and the plastic strain at fracture.

These conclusions apply so long as there is no complication arising from the intrusion of a precipitate that becomes the controlling stress concentrator.

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Gravimetric Determination of Sulphur in Basic Steelmaking Slags

By the

Methods of Analysis Committee

SYNOPSIS

A gravimetric method for the determination of sulphur in slag, including a perchloric acid fuming technique, is recommended; baking in *aqua regia* solution has also been shown to provide acceptable results. In the presence of barium, treatment of the insoluble residue is necessary to avoid error. 743

In 1949, the Sulphur Working Party of the Steel Practice Committee of the Steelmaking Division of the British Iron and Steel Research Association issued a report which showed that sulphur determination by routine methods in different laboratories produced figures which varied so widely that subsequent calculation of sulphur partition coefficients was invalidated.

The project was therefore referred to the Blast Furnace Raw Materials and Slags, Steelmaking Slags, and Refractories Analysis Sub-Committee for the development of a rapid and reliable method for the determination of sulphur in slag. Although, for control purposes in melting-shop laboratories, this was the main requirement, it was necessary first to produce a reliable standard method as a basis of comparison.

The constitution of the Sub-Committee is given in Appendix II.

PRELIMINARY WORK

To expedite the completion of the work, two groups were appointed to consider the different aspects of the problem. The combustion technique was chosen for development as a rapid method; the group examining this temporarily used, as a basis of comparison, a gravimetric method involving solution in *aqua regia* in the presence of potassium chlorate and bromine, dehydration of the silica residue by baking, re-solution in hydrochloric acid, evaporation to low bulk (10 ml.), dilution, filtration, and precipitation with barium chloride. Satisfactory results were obtained on five basic slags with sulphur contents between 0·18% and 0·51%; a detailed report on this research will be published later.

A gravimetric method on similar principles was examined by the other group, but results on one particular slag (containing fluorine and barium sulphate) were not satisfactory, and it was found that, in the presence of barium salts, pre-precipitation of barium sulphate could occur. If this happens before or during filtration of the silica residue, low results will be obtained unless the sulphur is recovered. This premature separation of sulphate by barium ions initially present in the solution appeared to be fortuitous, depending upon a critical balance of acidity, temperature, time, and concentration. The earlier method of the combustion group apparently gave correct results because this balance of critical features was slightly more favourable.

Another method that was put forward was based on perchloric acid dehydration. With this procedure, fluorine is expelled more efficiently, and barium compounds are brought into solution by a fuming treatment. It was realized that even with perchloric acid there was a possibility of premature precipitation of barium sulphate, and that any accurate method must involve examination of the residue.

It was also suggested that an alkali fusion procedure,

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Table I

SULPHUR CONTENT OF A BARIUM-CONTAINING SLAG, %

Method	*A*	*B*	*C*	*D*
Analyst				
1	0·39	0·41	0·35	0·46
2	0·40	0·41	0·39	0·41
3	0·37	0·39	0·39	0·40
4	0·39	0·39	0·39	...
5	0·395	...	0·40	...
6	0·355	0·38	0·365	0·39
7	0·39	0·395	0·395	0·455
8	0·39	0·41	0·40	0·27

depending on the decomposition of the slag by sodium carbonate fusion at 1000° C. in a platinum crucible, followed by water extraction, filtration, acidification, and precipitation with barium chloride, would give satisfactory results.

COMPARISON OF METHODS

Since some members were able to obtain reasonably concordant results using either of the methods, a further sample of barium-containing slag was circulated. Sulphur was determined using four variations of the gravimetric procedure to assess their respective value (*see* Table I). Method *A* involves perchloric acid fuming; method *B* uses *aqua regia* decomposition and baking, and also includes evaporation after filtration of the siliceous residue; method *C* is similar to *B*, but omits evaporation; and method *D* is an alkali fusion procedure.

With method *B*, involving the evaporation after separation of silica, a precipitate or turbidity was often produced, which proved to be a hydrolysis product consisting of titanium, aluminium, iron, and some sulphur. This was avoided in method *C*, which omits the evaporation, although filtration had to be completed quickly.

In the absence of an oxidant, the alkali fusion method yielded unsatisfactory figures (the low result reported for analyst No. 8 was shown to be due to the incomplete conversion of sulphide to sulphate), but it was thought advisable to examine it further.

Table II

SULPHUR CONTENTS OF SLAGS, %

Method	*MGS*/140			*MGS*/147		
	A	*B*	*D*	*A*	*B*	*D*
Analyst						
1	0·395	0·39	0·39	0·155	0·16	0·185
2	0·37	0·385	0·39	0·13	0·135	0·135
3	0·385	0·38	0·40	0·155	0·155	0·165
4	...	...	0·40	0·165	0·165	0·185
5	0·40	0·395	0·385	0·165	0·165	0·165
6	0·39	0·39	...	...	...	...
7	0·38	0·38	0·38	0·13	0·14	0·17
8	0·385	0·38	0·41	0·16	0·16	0·17
9	0·39	0·41	0·46	...	...	...
10	0·40	0·395	0·37	0·16	0·155	0·16
11	0·41	0·40	0·395	...	...	...
12	0·365	0·39	0·40	0·15	0·15	0·155

Table III

RECOVERY OF BARIUM SULPHATE FROM SLAGS

Method	Barium Sulphate, mg.			
	Present		Recovered	
	Sulphur Equivalent in Slag	Added	Total* (less blank)	Added
Perchloric acid	51·4	14·6	66·4	15·0
(Blank 1·6 mg.)	51·4	29·2	80·8	29·4
Aqua regia + baking	51·4	14·6	65·2	14·4
(Blank 2·4 mg.)	51·4	29·2	81·4	30·0
Perchloric acid	55·5	...	*s.* 55·8	...
	55·5	48·0	*s.* 60·0	
			r. 43·4	
			103·4†	47·6
Aqua regia + baking	55·5	...	*s.* 55·2	...
	55·5	48·0	*s.* 51·6	
			r. 51·4	
			103·0†	47·8
Alkali fusion	27·8	...	28·6	...
	27·8	48·0	77·0	48·4
Barium recovery as barium sulphate from above samples			3·4	...
			51·8	48·4

* *s.* = solution, *r.* = residue
† Barium recovery as $BaSO_4$ = 42·0 and 53·8 mg. respectively

Two more slags were therefore treated by methods *A* (perchloric), *B* (*aqua regia* + baking), and *D* (alkali fusion with oxidant). The results are given in Table II.

A high blank was often obtained on the fusion method, and it was felt that solution methods *A* and *B* were more convenient in operation, and were capable of giving satisfactory results.

SULPHUR IN THE PRESENCE OF BARIUM

Since some basic slags contain barium, derived from fluorspar impurities, consideration was given to the complete recovery of sulphur in such slags. A residue treatment was therefore introduced into the method, and tests were carried out using slags of known sulphur content to which further barium sulphate was added, in amounts much higher than those likely to be experienced in practice.

Both the perchloric fuming and the *aqua regia* baking techniques were employed, and, as a further check, a fusion method described by Lundell, Hoffmann, and Bright* was used.

The results obtained are summarized in Table III.

* G. E. F. Lundell, J. I. Hoffmann, and H. A. Bright, "The Chemical Analysis of Iron and Steel," p. 570: 1946, New York, John Wiley and Sons.

Table IV

SULPHUR CONTENT OF SLAGS, %
(Determined by Method Given in Appendix I)

Analyst	*MGS*/147		*MGS*/191		*MGS*/192	
	A	*B*	*A*	*B*	*A*	*B*
1	0·155	0·155	0·29	0·285	0·42	0·405
2	0·17	0·175	0·29	0·295	0·425	0·43
3	0·15	...	0·285	...	0·42	...
4	0·18	0·175	0·29	0·29	0·41	0·415
5	0·165	0·165	0·295	0·29	0·43	0·42
6	0·15	0·16	0·28	0·28	0·40	0·41
7	...	0·165	...	0·28	...	0·41
8	0·16	0·16	0·30	0·30	0·425	0·425
9	0·15	...	0·29	...	0·425	...
10	0·165	0·17	0·29	0·29	0·40	0·40
Av.	0·16	0·165	0·29	0·29	0·42	0·415
Range	0·03	0·02	0·02	0·02	0·03	0·03

A **= Perchloric acid, *B* = *Aqua regia* + baking**

These results indicated that complete recovery of barium sulphate was obtained by the residue treatment; an additional conclusion was that no advantage was gained by calculating the insoluble sulphur from the barium ion.

This investigation also disclosed that some supplies of sodium carbonate and perchloric acid contained appreciable amounts of sulphur compounds and made an important contribution to the blank correction required.

The findings were confirmed by the four members of the group on four further slags, on which the following ranges of results of percentage sulphur were found:

Sample	Perchloric Acid Fuming	*Aqua regia* + Baking
MGS/101	0·17 – 0·185	0·17 – 0·18
MGS/133	0·34 – 0·35	0·34 – 0·35
Parkgate 1	0·49 – 0·51	0·495– 0·50
Parkgate 2	0·555– 0·57	0·56 – 0·58

FINAL TRIALS

A more comprehensive trial of the method finally approved was carried out on three slags specially selected for this purpose, with the results shown in Table IV.

These figures are considered to give satisfactory confirmation of the accuracy of the method recommended in Appendix I for the determination of sulphur in slag. The *aqua regia* + baking alternative may be preferred in certain laboratories.

APPENDIX I

Recommended Gravimetric Method for Sulphur in Slag

Solutions Required

Bromine water (saturated)
Hydrochloric acid (1:9)
Barium chloride (10%)
Acid wash—50 ml. of hydrochloric acid (sp. gr. 1·16) and 10 ml. of barium chloride solution (10%) diluted to 1 l.

Procedure

To 2 g. of sample (*see* Note 1) add 0·2 g. of anhydrous sodium carbonate (Note 2), 10 ml. of bromine water, and 35 ml. of nitric acid (sp. gr. 1·42). Add cautiously 25 ml. of hydrochloric acid (sp. gr. 1·16) and heat until decomposition is apparently complete. Add 15 ml. of perchloric acid (sp. gr. 1·54—Note 3), fume for 2 or 3 min., cool and dilute with 45 ml. of water. Filter on an ashless paper pulp pad, wash alternately with water and dilute hydrochloric acid (1:9), and dilute the filtrate to 200 ml. (Note 4).

Boil for 2 min., add 20 ml. of barium chloride solution (10%), and allow to stand overnight. Filter on an ashless paper pulp pad, wash with acid-wash solution and then with water until free from chlorides, transfer the pad and precipitate to a platinum crucible, char, burn off the carbon at a low temperature, and ignite at 800–900° C. Brush the precipitate on to a tared watch-glass and weigh as $BaSO_4$.

Notes

(1) Below 0·2% of sulphur, use 3-g. sample; above 0·5%, use 1 g. or less.

(2) Particular care should be taken to use apparatus and reagents free from sulphur compounds. The former should be cleaned with boiling hydrochloric acid, washed, and reserved for sulphur determination, and the latter should be stored separately away from laboratory fumes. A blank should be carried through with each assay.

(3) Alternatively, omit perchloric acid, evaporate to dryness, and bake at 300° C. for ½ hr. Cool, add 20 ml. of hydrochloric acid (sp. gr. 1·16), evaporate to dryness, and bake as before. Cool and take up in 15 ml. of hydrochloric acid (sp. gr. 1·16), boil, add 45 ml. of hot water, boil, filter, and continue as in the second paragraph of the 'Procedure'.

(4) If the slag contains barium, the siliceous residue should be examined as follows:

Transfer the filter and residue to a platinum crucible, dust with 0·05 g. of Na_2CO_3, and ignite at 550–600° C., cool, and treat with 2 ml. of nitric acid (sp. gr. 1·42), 4 ml. of hydrofluoric acid, and 2·5 ml. of perchloric acid (sp. gr. 1·54). Evaporate to dryness, fuse with 2 g. of anhydrous sodium carbonate, leach out with water, filter, and wash. Make the filtrate just acid with hydrochloric acid, boil, and add to the main solution.

APPENDIX II

Constitution of the Sub-Committee at 31st March, 1952

G. E. SPEIGHT (*Chairman*)	The United Steel Companies, Ltd.
B. BAGSHAWE	Brown-Firth Research Laboratories
E. W. HARPHAM, I. HERBERT	Richard Thomas and Baldwins, Ltd.
W. H. HESSON	Appleby-Frodingham Steel Co.
A. P. LUNT	Park Gate Iron and Steel Co., Ltd.
D. MANTERFIELD	Steel, Peech and Tozer
N. D. RIDSDALE	Bureau of Analysed Samples, Ltd.
C. W. SHORT	J. Lysaght, Ltd.
J. L. WEST	Hadfields, Ltd.
T. H. WILLIAMS	Stewarts and Lloyds, Ltd.
E. C. V. WISKAR	Dorman Long and Co., Ltd.

CORRESPONDENCE

Further Correspondence on the Paper—

HETEROGENEOUS NUCLEATION OF GRAPHITE IN HYPO-EUTECTOID STEELS*

By W. E. Dennis

Mr. **W. C. Leslie** (United States Steel Company) wrote: The last sentence of Mr. Dennis's paper reads:

> "It is suggested that the observed formation of chain graphite in welded specimens along the Ac_1 isotherm results from the segregation of aluminium which must occur, it being some 30 times more soluble in ferrite than in austenite at that temperature."

To the best of my knowledge, the distribution coefficient of aluminium in austenite and ferrite, at equilibrium, has not been determined. The published aluminium–iron phase diagrams†‡ indicate that the $\gamma + \alpha$ field must be very limited in extent, so that the distribution coefficient of aluminium in austenite and ferrite must be close to unity, rather than about 30 as implied by Mr. Dennis.

Quite apart from consideration of the distribution coefficient, it is difficult to imagine that much segregation of aluminium in ferrite occurs during a welding operation.

AUTHOR'S REPLY

Dr. **W. E. Dennis** wrote in reply: The suggestion quoted by Mr. Leslie is misleading only when it is divorced from the subject to which it referred. In my paper, this suggestion was made in reference to a *ternary* iron–carbon–aluminium alloy under a *steep temperature gradient*. Mr. Leslie's remarks, based on the *binary* iron–aluminium *equilibrium* diagram and on deductions that are valid only for compositions where the tangent to the γ-loop is nearly parallel to the temperature axis, are therefore completely irrelevant.

It must also be emphasized that my hypothesis required only that a small number of aluminium atoms should be segregated in such a way as to facilitate the formation of alumina nuclei by the diffusion of oxygen atoms through the grain boundaries during graphitization.

Letter to the Editor

IDENTIFICATION OF CERTAIN IRON–SILICON CARBIDES

The unusual constituent discovered by Owen and Street[1] during the course of their examination of the carbide phase in high-purity iron–carbon–silicon alloys, which they suggested might be an iron–silicon carbide, has some resemblance to an acicular constituent that I observed some time ago during an examination of a carburized nickel–chromium–molybdenum steel.

Chemical analysis of drillings taken from the carburized face and the interior of this steel gave the following results:

Composition, %	At Face	2 in. Below Face
C	1·07	0·49
Si		0·17
Mn		0·36
Ni		3·67
Cr		1·99
Mo		0·15

The structure observed at a location immediately below the carburized face of the specimen, after etching in a boiling solution of alkaline sodium picrate, is shown in Fig. 1, and that observed at the same point after etching electrolytically in a 20% aqueous solution of chromic acid is illustrated in Figs. 2 and 3. The structure developed on etching the steel electrolytically in chromic acid was somewhat unusual. The easily recognizable portion of the pro-eutectoid carbide was present in a finely dispersed form and occurred partly along the grain boundaries and partly in the body of the grains. The acicular phase that was also present could not be identified definitely by means of the microscope. This phase was present only in the vicinity of the carburized face of the specimen, and the number of needles per unit area decreased continuously with increasing distance from this face, no needles being observed at a depth greater than about 0·4 in. below the carburized face.

It was thought at first that the acicular phase might be a complex nitride. Spectrographic analysis, however, revealed that the chemical composition of the steel was not unusual, and nitrogen determinations made on samples taken from the carburized and uncarburized regions of the specimen indicated that the (combined) nitrogen content at both locations was lower than that normally found in steels of this type (0·001%, as opposed to a normal average of 0·002–4%), suggesting that the acicular phase was not nitrogenous. X-ray examination of the carburized face of the specimen also failed to indicate the presence of any large quantity of nitride.

* *J. Iron Steel Inst.*, 1952, vol. 171, pp. 59–63.
† "Metals Handbook," p. 1161: 1948, Cleveland, Ohio, American Society for Metals.
‡ C. J. SMITHELLS: "Metals Reference Book," p. 279: 1949, London, Butterworths Scientific Publications.

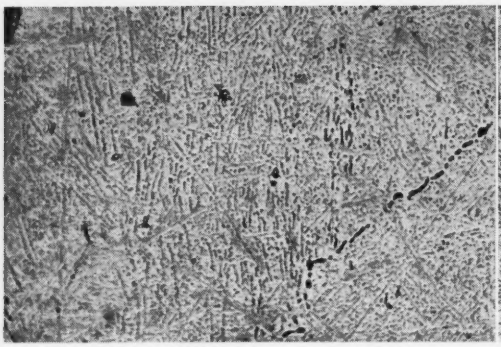


Fig. 1—Structure immediately below face of carburized specimen, after etching in a boiling solution of alkaline sodium picrate × 500

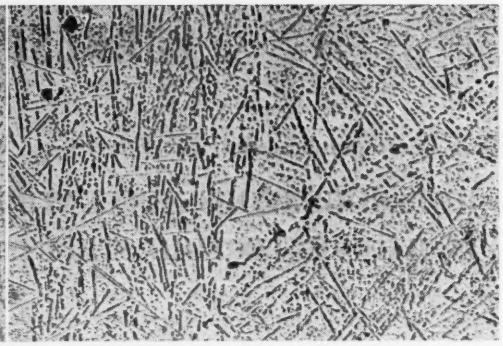


Fig. 2—Structure immediately below face of carburized specimen, after etching electrolytically in a 20% aqueous solution of chromic acid × 500

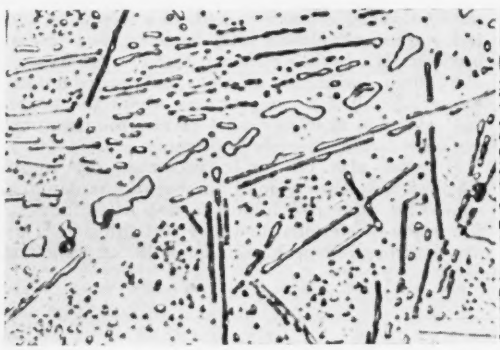


Fig. 3—Structure at a location along boundary line *AB* of Fig. 2 × 2000

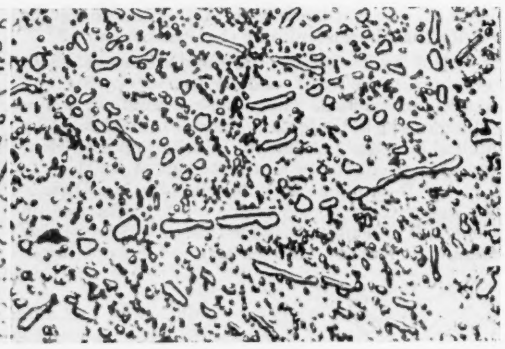


Fig. 4—Structure of annealed specimen, etched electrolytically in a 20% aqueous solution of chromic acid × 2000

The X-ray examination indicated that in the carburized zone the steel was essentially a mixture of austenite and α-iron, the austenite being of large grain size and constituting about 40% of the whole. However, no change in the appearance of the needles could be detected in two specimens taken from the carburized face, one of which was maintained for 5 hr. in liquid air and the other for 80 hr. at 400° C. This confirmed that the needles were neither austenite nor martensite but were particles of some separate discrete phase.

These results suggested that the acicular constituent might be a carbide, and examination of sections of the carburized face, water-quenched after 30 min. at temperatures of 800°, 950°, 975°, 1000°, and 1050° C., showed that solution of the needles was about 90% complete at 975° C., suggesting that the needles, if carbide, were probably complex in nature and relatively insoluble. When a section taken from the carburized face was annealed at 770° C. for 24 hr. and then cooled from that temperature at about 10° C./hr., some spheroidization of the needles occurred, as shown in Fig. 4. The partially spheroidized structure so obtained resembled, in some ways, that found in other similar hypereutectoid steels after the same annealing treatment. It therefore seems probable that the acicular constituent that I observed in the carburized Ni–Cr–Mo steel was a complex carbide, although—in view of the analysis of the steel—it is difficult to associate this carbide chemically with the iron–silicon carbide observed by Owen and Street. It would seem to be more closely akin to the acicular cementite obtained by Jolivet[2] in a specimen of a 0·75% C, 0·75% Mn, 1% Cr, 0·6% Mo steel isothermally transformed at 500° C., and to that obtained by Mehl, Barrett, and Smith[3] in slowly cooled specimens of a 1·3% C steel.

The iron–silicon carbide observed by Owen and Street was precipitated in a Widmanstätten pattern in low-carbon high-silicon alloys melted *in vacuo* and cooled at 300° C./hr. It was impossible, however, to precipitate the acicular phase in specimens taken from the carburized face of the Ni–Cr–Mo steel and cooled at three different rates (water-quenching, air-cooling, and furnace-cooling at 30° C./hr.) from temperatures at which the carbide was initially in complete solution in the austenite. This result suggests that the acicular phase observed in the carburized Ni–Cr–Mo steel, although similar in appearance and dispersion to the iron–silicon carbide discovered by Owen and Street, may have been different in composition and mode of formation.

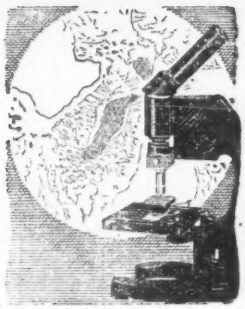
The work described in this note was carried out in the Metallurgy Division of the National Physical Laboratory, and it is published by kind permission of the Director of the Laboratory.

W. I. PUMPHREY

Murex Welding Processes Ltd.,
Waltham Cross,
Herts.

1. W. S. OWEN and B. G. STREET: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 15–18.
2. H. JOLIVET: *J. Iron Steel Inst.*, 1939, No. II, pp. 95P–114P.
3. R. F. MEHL, C. S. BARRETT, and D. W. SMITH: *Trans. Amer. Inst. Min. Met. Eng.*, 1933, vol. 105, pp. 215–249.

Continuous-Cooling Transformation Diagrams of Steels



By W. Steven, Ph.D., F.I.M., and G. Mayer, B.Sc., A.I.M.

SYNOPSIS

A method is described for the determination of continuous-cooling transformation diagrams that portray the course of transformation with temperature in 1–6-in. dia. bars quenched in oil. Diagrams are presented for samples of B.S. En 12, 16, 17, 19, 23, 26, 111 and 160 steels, together with closely comparable isothermal transformation diagrams for the B.S. En 12 and 19 samples. Information derived from oil-quenched bars from isothermal transformation diagrams and from end-quench hardenability curves is compared with that provided by the continuous-cooling transformation diagrams. 746

ISOTHERMAL transformation diagrams are of value for many research purposes and for the design of some special heat-treatments, but the information that they provide is not readily applicable to heat-treatments involving transformation under continuous-cooling conditions, and the bulk of commercial heat-treatment falls into this category. There is therefore a need for diagrams that will portray the transformations that occur in steels during continuous cooling from an austenitizing temperature, in as clear a manner as an isothermal diagram portrays the progress of transformation at constant temperatures.

Liedholm[1] has published a number of continuous-cooling diagrams, each of which was obtained by hardness testing and by microscopically examining Jominy test specimens that were end-quenched for different periods and then totally quenched to room temperature to freeze the structures developed during end-quenching. It is experimentally difficult, however, to obtain detailed and accurate information by this method; furthermore, the method of presentation adopted by Liedholm makes his diagrams difficult to interpret. Manning and Lorig[2] have also used the end-quench test to derive diagrams that show the influence of rate of cooling on the temperature at which transformation starts during continuous cooling.

Continuous-cooling diagrams of a kind were also published at much earlier dates by those investigators[3, 4, 5] who studied the effect of cooling rate on the Ar_1, Ar′, and Ar″ transformation temperatures. These diagrams provide useful information on the behaviour of steels during continuous cooling, but they lack detail.

The diagrams presented in this paper portray, for a selection of B.S. En steels, the progress with temperature of the transformations that occur in bars up to 6-in. dia. when quenched in oil under standard conditions. Provided that the relevant information on cooling rates is available, the diagrams can also be used to indicate the transformation behaviour of bars of the steels when quenched in oil under significantly different conditions.

The cooling cycles associated with oil-quenching were simulated by the method described by Steven and Mayer,[6] which involves air-cooling bars of appropriate sizes. Transformations were followed mainly by a dilatometric method, but confirmatory and supplementary information was obtained by microscopic methods.

MATERIALS TESTED

The analyses and grain sizes of the steels studied, all of which were manufactured commercially, are shown in Table I. The samples of four of the steels [B.S. En 16, 17, 23 and one of the B.S. En 26 steels (F)] were obtained from the same billets as those used to determine the diagrams in the "Atlas of Isothermal Transformation Diagrams of B.S. En Steels."[7] Isothermal transformation diagrams have also been published for the other B.S. En 26 steel (G) and for the B.S. En 111 and 160 steels.[8] Diagrams for the two remaining steels (B.S. En 12 and 19) are presented in Figs. 15*a* and *b*. These were determined using specimens machined from the batches of $\frac{5}{8}$-in. dia. hot-rolled bar produced for the determination of the intermediate portions of the corresponding continuous-cooling transformation diagrams. The isothermal transformation diagram for the B.S. En 12 steel was determined wholly by the microscopic method, and that for the B.S. En 19 steel was determined by the dilatometric method supplemented where necessary by microscopic tests. The thicker broken line in the pearlite range of the diagram for the B.S. En 12 steel indicates the appearance in the microstructure of carbide as distinct from ferrite.

Paper MG/AG/194/52 of the Thermal Treatment Sub-Committee of the Alloy Steels Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 15th December, 1952. The views expressed are the authors', and are not necessarily endorsed by the Sub-Committee as a body.

Dr. Steven and Mr. Mayer are on the staff of the Development and Research Department, The Mond Nickel Company, Ltd., Birmingham.

Table I

ANALYSES, GRAIN-SIZES, AND AUSTENITIZING TEMPERATURES OF STEELS STUDIED

Mark	B.S. En No.	Chemical Composition, wt.-%								'As-Quenched' Grain Size (A.S.T.M.)	Austenitizing Temperature, °C.
		C	Si	Mn	S	P	Ni	Cr	Mo		
A	12	0·43	0·21	0·95	0·024	0·018	0·93	0·15	0·04	6	845
B	16	0·33	0·18	1·48	0·028	0·028	0·26	0·16	0·27	7	845
C	17	0·38	0·25	1·49	0·028	0·036	0·24	0·10	0·41	8	845
D	19	0·44	0·22	0·60	0·023	0·023	0·24	1·19	0·37	6	850
E	23	0·32	0·28	0·61	0·013	0·018	3·22	0·63	0·22	7	835
F	26	0·42	0·31	0·67	0·022	0·029	2·53	0·72	0·48	6–7	835
G	26	0·38	0·15	0·56	0·005	0·011	2·42	0·74	0·46	8	835
H	111	0·35	0·13	0·65	0·032	0·035	1·27	0·55	Nil	7	845
I	160	0·41	0·13	0·48	0·043	0·016	1·75	0·17	0·22	6–7	845

End-quench hardenability curves, determined on specimens machined from $1\frac{1}{8}$-in. dia. hot-rolled bar of those steels for which the standard Jominy test was suitable, are presented in Fig. 1.

EXPERIMENTAL PROCEDURE

To simulate the oil-cooling of bars up to 6-in. dia., it is necessary to air-cool bars up to about 0·8-in. dia., and consequently the dilatometer used was of a more robust type than is usual. The design adopted (Fig. 2) was of the simple push-rod dial-gauge type, but to provide the requisite strength and to minimize the retarding effect of the dilatometer on the cooling rates of the specimens, the conventional outer tube was replaced by three symmetrically placed silica rods *a*, supporting a triangular-shaped silica base *b*, which carried the plug *c*, on which the dilatometer specimens *d* rested. The other details of the dilatometer were substantially conventional.

The diameters of the dilatometer specimens were varied to achieve cooling rates equivalent to those of 1·7–6-in. dia. bars quenched in oil. These diameters and the other dimensions of the specimens are shown in Table II, which also indicates the size of hot-rolled bar from which each size of test specimen was machined. The effects of 'end-cooling' on the larger test specimens were eliminated by providing axial holes *e* at each end of the test specimens to receive the dilatometer push rod *f* and the bottom plug *c* (specimen *A*, Fig. 2). The depths of these holes were equal to the diameter of the specimen, and consequently those parts of the test bar affected by end-cooling were not included in the test length for which dimensional changes were recorded. It was not possible to use this method to avoid the effects of end-cooling on the smaller diameter test specimens, and the design used for test specimens of less than 0·25-in. dia. is illustrated as specimen *B* in Fig. 2. However, the effects of 'end-cooling' were less with these specimens, because of their greater lengths in proportion to their diameters (Table II).

The main surfaces of the dilatometer test specimens were electroplated with a 0·0007–0·001-in. thick layer of nickel and, to prevent flaking of the plating during the dilatation tests, each plated specimen was given a preliminary degassifying treatment of 16 hr. at 200° C. Check tests confirmed that the nickel plating effectively prevented decarburization.

Temperatures were measured by a galvanometer and calibrated scale used in conjunction with a Pt/Pt–10% Rh thermocouple, which was spot welded to the surface of each dilatometer test specimen. The wires, which were 0·010-in. dia., were welded separately to the specimens, with the latter forming a short bridge between the wires.

The dilatometer specimens were austenitized, while in position in the dilatometer (Fig. 2), in a tubular resistance furnace *g*. A stop-watch *h* was mounted beside the dial gauge *i*. During the austenitizing period, the temperature of the furnace was maintained by a differential expansion controller to within ± 3° C. of the nominal value. After the austenitizing treatment, the furnace was lowered away from the dilatometer and a baffle *j* was pushed into position to screen the dilatometer from the hot furnace. The specimen was then allowed to cool freely in the dilatometer within the enclosed chamber *k*. Dial gauge and

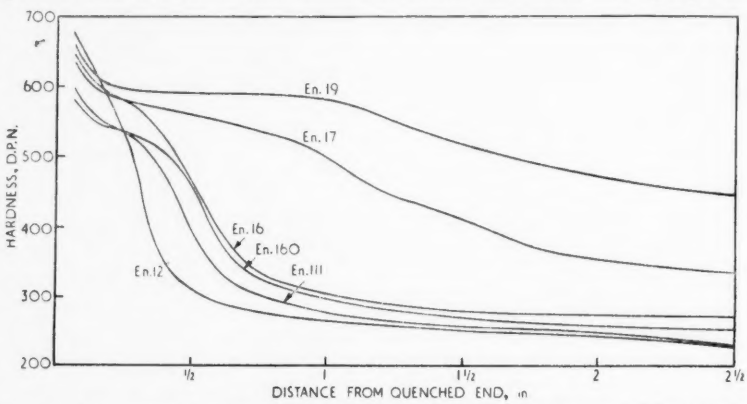


Fig. 1—End-quench hardenability curves for 1-in. dia. test-bars machined from $1\frac{1}{8}$-in. dia. rolled bar

time readings were recorded photographically at closely spaced temperature intervals, by means of a cine-camera that was capable of taking a series of single exposures and was manually operated by a remote-control push-button mechanism. As the galvanometer spot passed each of the selected temperature graduations, a photograph was taken of the stop-watch and dial-gauge readings.

The time/temperature records, down to the temperature at which transformation started, provided a check on the accuracy with which the desired cooling schedule had been achieved. Those obtained from specimens that transformed wholly to martensite were used to make a slight correction to allow for the fact that the air-cooling conditions for the dilatometer samples were not quite the same as those used in deriving the published relationship between air-cooled and oil-cooled bars. A given size of bar cooled slightly more slowly in the dilatometer than when allowed to cool freely in air. This was due mainly to the higher temperature of the air surrounding the specimens, which was caused by the heat emitted from the dilatometer parts and from the adjacent austenitizing furnace.

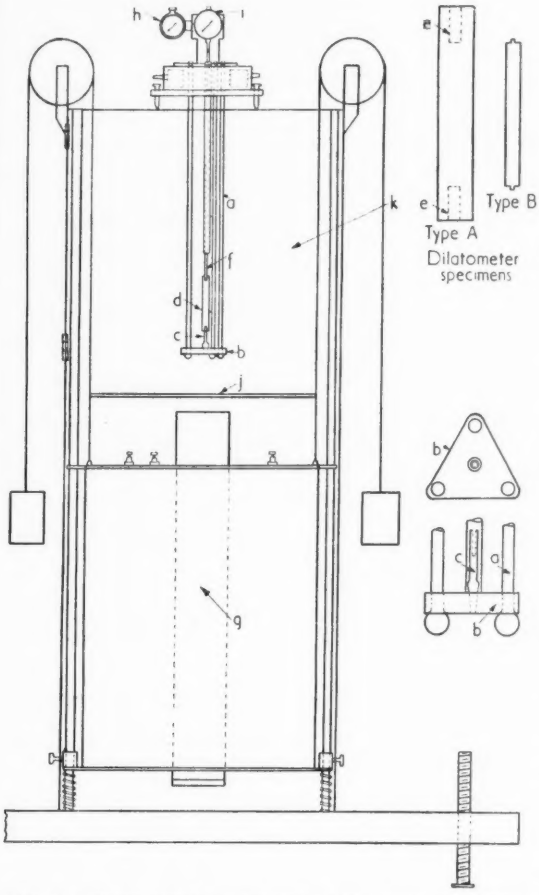


Fig. 2—Dilatometric apparatus, with types of dilatometer specimen

Table II

DIMENSIONS OF DILATOMETER SPECIMENS AND EQUIVALENT O.Q. BAR DIAMETERS

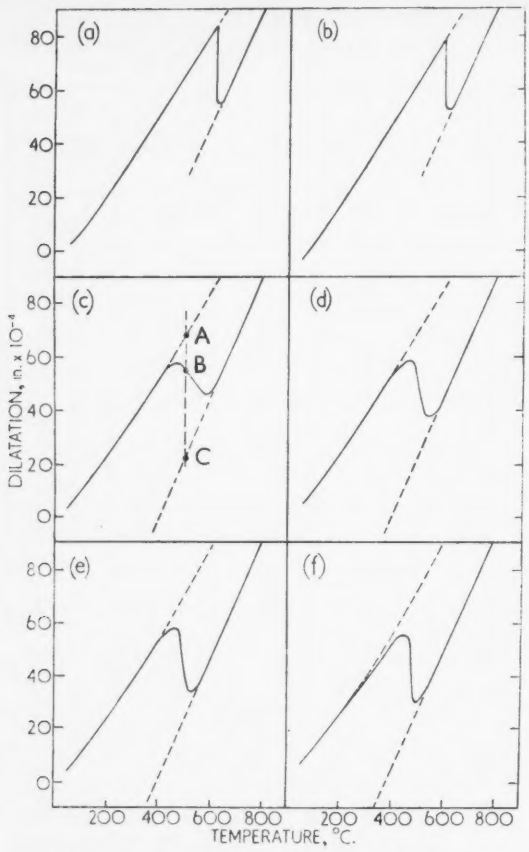
Diameter of Specimen, in.	Effective Length of Specimen, in.	Diameter of Bar from which Machined, in.	Type of Specimen*	Equivalent Oil-Quenched Diameter, in.
0·10	2	$\frac{3}{8}$	B	1·7
0·13	,,	,,	,,	2·0
0·16	,,	,,	,,	2·3
0·19	,,	,,	,,	2·5
0·22	,,	,,	,,	2·8
0·25	,,	,,	,,	3·0
0·28	,,	,,	A	3·25
0·31	,,	,,	,,	3·4
0·34	,,	,,	,,	3·6
0·38	,,	$\frac{5}{8}$	,,	3·9
0·42	,,	,,	,,	4·1
0·46	,,	,,	,,	4·35
0·50	,,	,,	,,	4·55
0·54	,,	,,	,,	4·8
0·58	,,	,,	,,	5·0
0·62	3	$1\frac{1}{8}$	,,	5·2
0·66	,,	,,	,,	5·4
0·70	,,	,,	,,	5·6
0·74	,,	,,	,,	5·8
0·79	,,	,,	,,	6·0

* *See* Fig. 1

Previous tests[6] had shown that the air-cooling rates over the temperature range 700°–300° C. were closely similar across the sections of bars up to at least 0·8-in. dia., but it was considered advisable to determine the magnitude of the temperature gradients developed across the sections of specimens while cooling through this temperature range. Accordingly, the temperature differences developed between the surface and the axis of an 0·8-in. dia. bar of a deep-hardening steel, which was air-cooling from 840° C., were recorded using a Pt/Pt–Rh differential thermocouple. The manner in which the difference varied with axis temperature is indicated in Table III. The maximum temperature difference, and therefore the maximum error introduced by recording only surface temperatures, is of the order of 13° C. However, this error will appear on the continuous-cooling diagram only if the 0·8-in. dia. dilatometer specimen (the largest used) transforms at about 700° C. If the steel transforms at a lower temperature, or if the test bar diameter is smaller, the error will be less. Consequently, over the greater part of the diagram the error due to temperature gradients is negligible.

Specimens that varied in diameter from 0·10 in. to 0·79 in. were used to obtain a set of dilatation curves for each steel; *i.e.*, for the cooling rates of the axes of 1·7–6-in. dia. bars quenched in oil. Each specimen was austenitized for 50 min., and the temperatures adopted are indicated in Table I. A dilatation curve was also determined for an annealed sample of each steel during cooling from a reheating temperature of 670° C.

The dilatation curves were found to be closely reproducible, and those features of the curves that would be expected to be independent of cooling rate—*e.g.*, the coefficients of expansion for the ferritic and austenitic conditions—were found to be independent of the test-piece diameter that controlled rate of



(*a*) 0·80-in. dia. test-piece ≡ 6·05-in. dia. O.Q. bar; (*b*) 0·58-in. dia. test-piece ≡ 5·0-in. dia. O.Q. bar; (*c*) 0·42-in. dia. test-piece ≡ 4·1-in. dia. O.Q. bar; (*d*) 0·25-in. dia. test-piece ≡ 3·0-in. dia. O.Q. bar; (*e*) 0·19-in. dia. test-piece ≡ 2·5-in. dia. O.Q. bar; (*f*) 0·10-in. dia. test-piece ≡ 1·7-in. dia. O.Q. bar

Fig. 3—Selection of dilatation/temperature curves for the B.S. En 111 steel

cooling. A selection of the dilatation curves used to derive the diagram for the B.S. En 111 steel is shown in Fig. 3.

It was noted that the austenite dilatation curve for all the steels tested was linear with temperature in the absence of transformation, whereas that for the steels in the ferritic condition was distinctly curved, particularly at temperatures below 250° C. The curves for the annealed samples cooling from 670° C. closely matched the lower portions of the curves for samples that did not form martensite during cooling from the austenitizing temperatures, and these curves were used to facilitate the quantitative interpretation of the results.

The principle adopted to estimate the degree of transformation of each sample at any temperature as it cooled from the austenitizing temperature is illustrated on the dilatation curve of Fig. 3*c*. The dilatation curve for the continuously cooled sample is indicated by a full line, and the upper broken line represents the dilatation curve of an annealed sample of the same steel cooling from 670° C. It was assumed that, at the temperature indicated by the intercept, the proportion of transformed austenite was indicated by the ratio *BC*/*AC*.

The temperature at which transformation started and had proceeded 10, 50, 75, 90, and 100% was read from each dilatation curve. In general, the beginning of transformation was clearly indicated by a distinct break in the dilatation curve; nevertheless, tests were made to confirm that the dilatometer was sufficiently sensitive to detect, under continuous-cooling conditions, the beginning of transformation.

Cylindrical specimens, to which thermocouples had been attached, were air-cooled to a temperature 10–15° C. above that at which the beginning of transformation was indicated on the dilatation curve; they were then quenched in water and their microstructures were examined. The dilatation curves for specimens simulating oil-cooling at the axial position of 2·0-in., 3·0-in., and 3·6-in. dia. bars of B.S. En 12 and for that of 2·0-in., 3·0-in., and 4·0-in. dia. bars of B.S. En 19 were checked in this manner. None of the quenched bars showed evidence that transformation had occurred during the air-cooling stage, thus indicating that the dilatometer had been sensitive enough to define the start of transformation to better than 10–15° C.; *i.e.*, within the limits of accuracy of the check tests. With the equipment available, it was not possible to time the quenching stage of these tests with sufficient accuracy to assess the sensitivity of the dilatometer more closely.

It is believed that the temperatures derived from the dilatation curves for the progress of transformation up to 95% are accurate to within ± 10° C., but the temperatures at which transformation was completed could not always be assessed with equal certainty; accordingly, they are indicated on the diagrams by broken lines.

The final microstructures of the dilatometer specimens were examined and their hardness values were determined. The latter are presented in Fig. 4, and have, for convenience, been plotted against equivalent oil-quenched bar diameter.

From previous work, it was anticipated that it would be possible to achieve the cooling rate of a 1-in. dia. oil-quenched bar by using a dilatometer sample of about 0·05-in. dia. Owing to the retarding effect of the apparatus on cooling rates, however, it proved impossible to achieve rates much in excess of that of a 1½-in. dia. bar, and it was necessary to use a microscopic method to obtain information on the behaviour of smaller bars.

Preliminary experiments showed that the cooling curve of a 0·054-in. dia. nickel-plated wire cooled in air was equivalent to that of the axis of a 0·9-in. dia.

Table III

TEMPERATURE GRADIENT ACROSS A 0·8-IN. DIA. A.C. BAR

Temperature of Axis, ° C.	Temperature Difference between Axis and Surface, ° C.
700	13
600	8·5
500	6
400	3
320	2

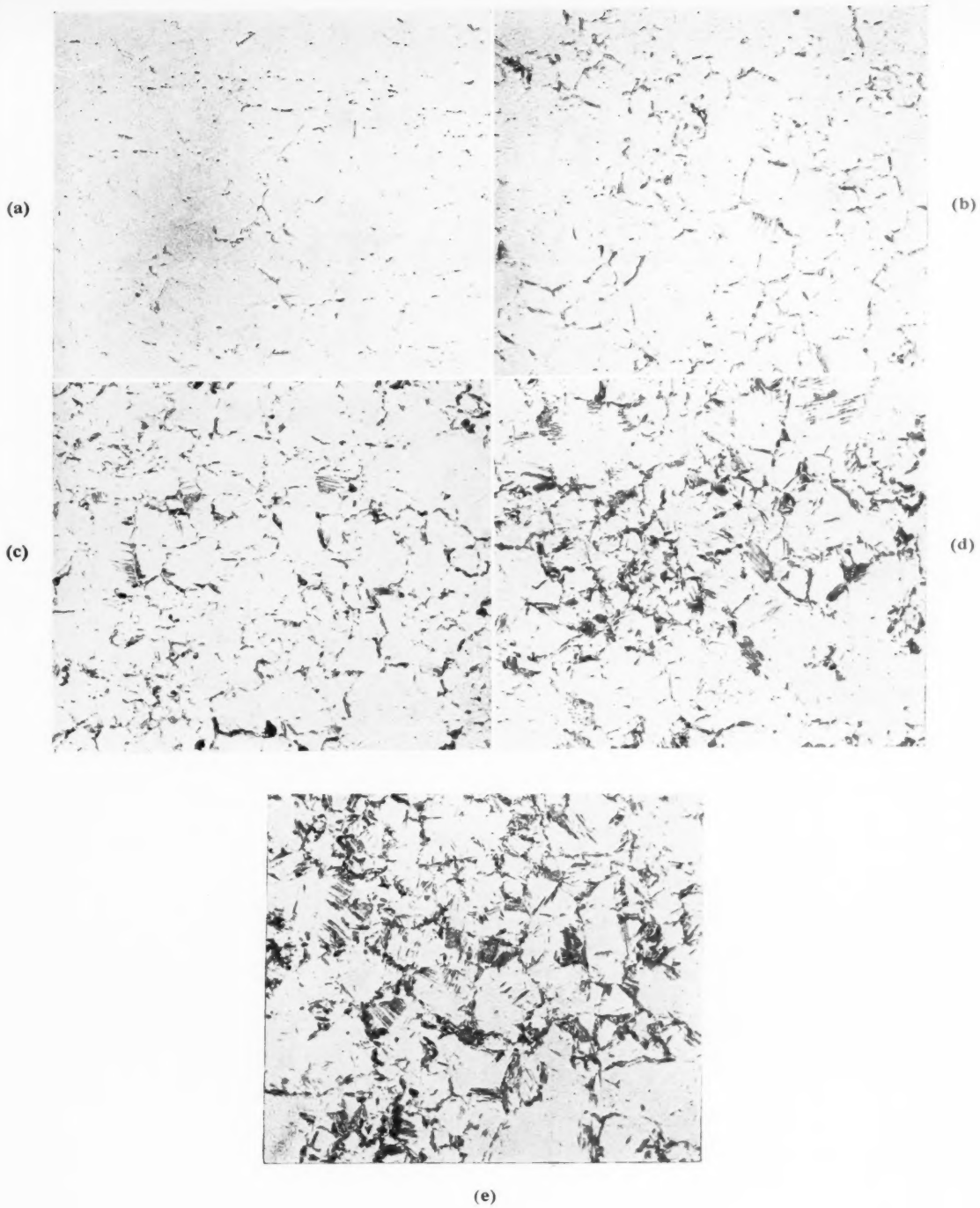
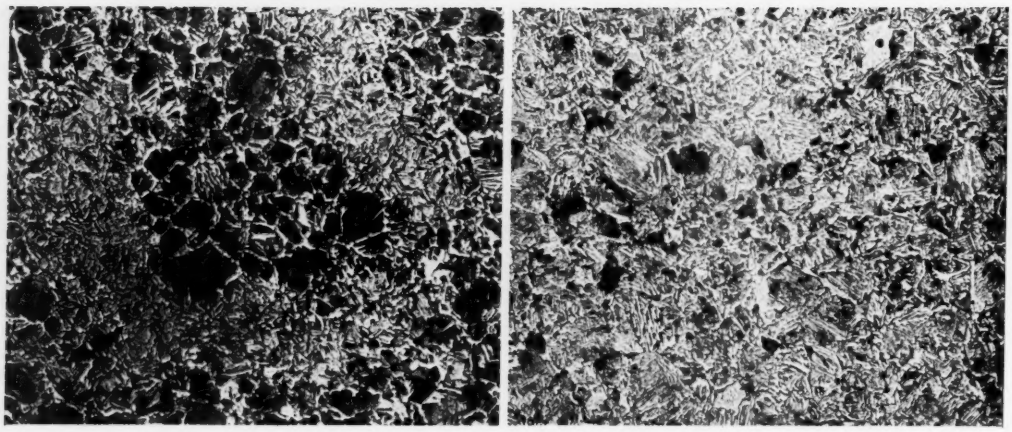


Fig. 5—Microstructures of 0·054-in. dia. specimens of the B.S. En 12 steel, air-cooled to (*a*) 540° C., (*b*) 500° C., (*c*) 450° C., (*d*) 400° C., and (*e*) 350° C., and then water-quenched



(a) (b)

Fig. 6—Microstructure of the B.S. En 12 steel : (*a*) At the axis of a 1·7-in. dia. O.Q. bar ; (*b*) A.C. dilatometer specimen corresponding to (*a*)

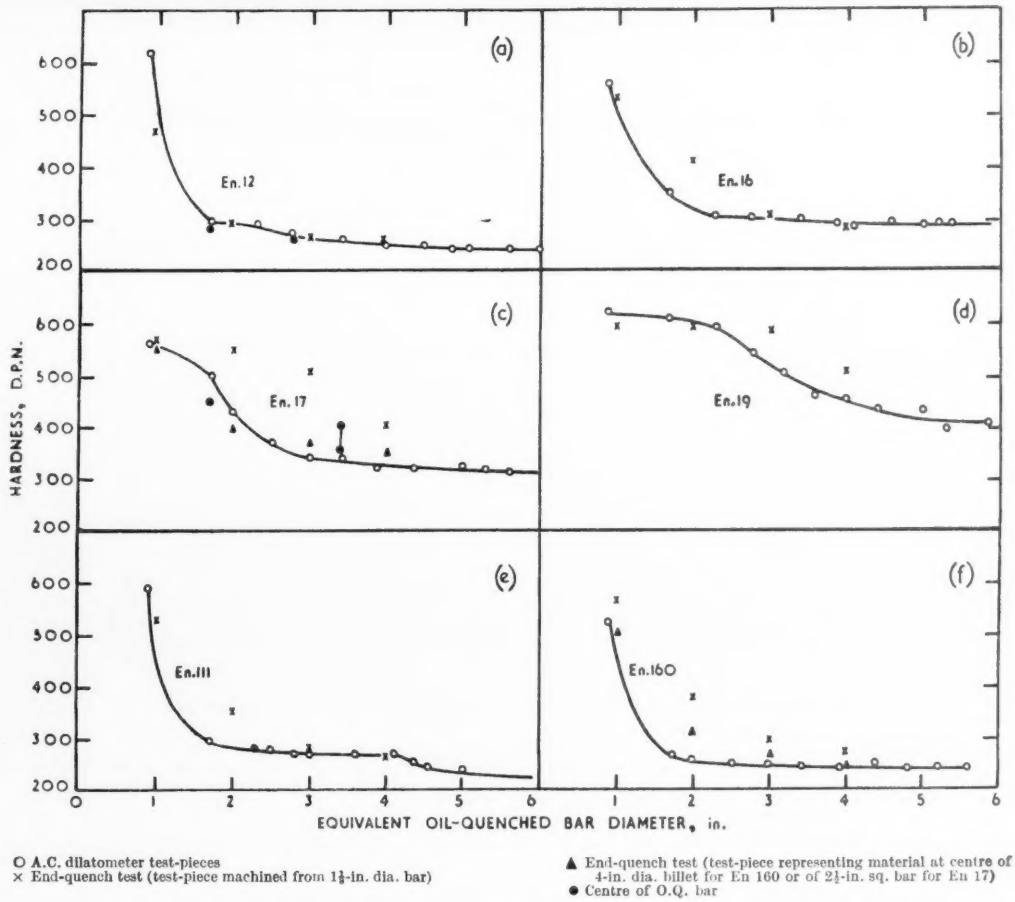


Fig. 4—Comparison of as-quenched hardness values obtained by different test procedures for the centres of O.Q. bars of steels (*a*) En 12; (*b*) En 16; (*c*) En 17; (*d*) En 19; (*e*) En 111; (*f*) En 160

bar quenched in oil. This was in satisfactory accord with previous results, which showed that unplated wire of this diameter was equivalent to a 1-in. dia. bar quenched in oil.[6]

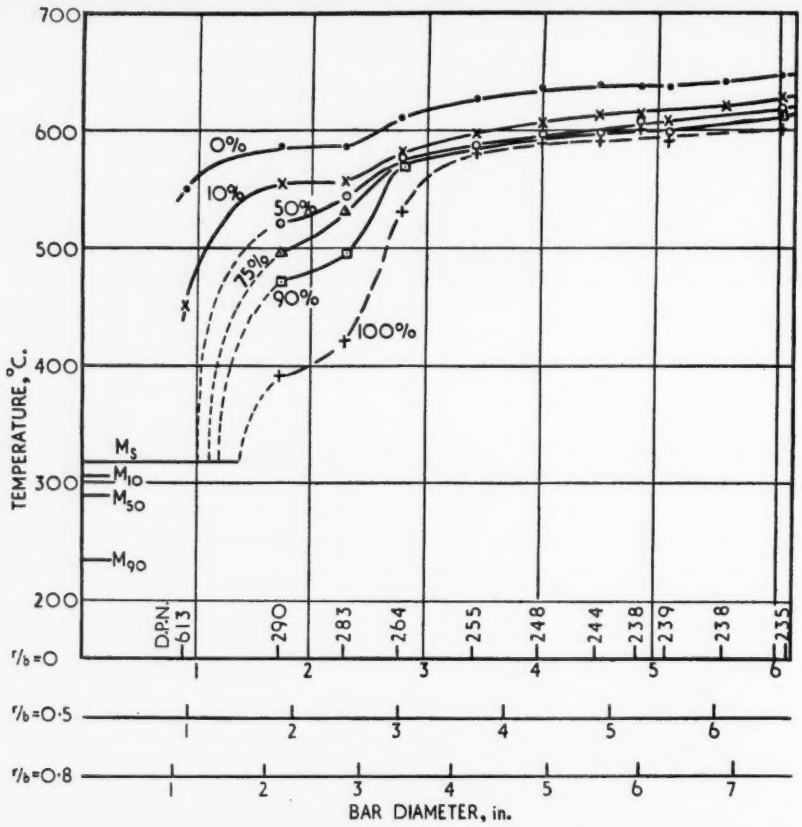
Samples 0·054-in. dia. × 1⅛-in. long were prepared from a ⅜-in. dia. hot-rolled bar of each steel. These were austenitized at the appropriate temperature and were then allowed to cool in an enclosed air chamber. The progress of cooling of each sample was followed by Pt/Pt–10% Rh thermocouple wires (0·005-in. dia.) welded to points about ¼ in. apart on each specimen and used in conjunction with the galvanometer and scale already mentioned. On reaching pre-determined temperatures, the specimens were quenched in water to provide for each steel a series of microstructures portraying the progress of transformation with falling temperature. The cooling rate of each specimen prior to transformation was checked from a photographic record of stop-watch readings taken at selected temperature intervals.

A typical series of microstructures showing the progress of transformation in a sample of the B.S. En 12 steel is shown in Fig. 5. The degree of transformation of each sample to products other than martensite was estimated visually with the help of standard charts portraying known degrees of transformation. The temperatures at which transformation started and had proceeded 10, 50, 75, 90, and 100% were derived by interpolation.

The M_s, M_{10}, M_{50}, and M_{90} temperatures for each steel were determined by the method described by Greninger and Troiano.[9]

CONSTRUCTION AND CONSIDERATION OF CONTINUOUS-COOLING TRANSFORMATION DIAGRAMS

The results of the dilatation and interrupted cooling tests on each steel were used to construct the diagrams presented in Figs. 7–14. The scales of these diagrams represent temperature of transformation and bar diameter, and the diagrams show the temperatures at which transformation starts and reaches various stages of completion (10, 50, 75, 90, and 100%) during oil-quenching from the austenitizing temperature.



[Fig. 7—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 12 steel, austenitized at 845° C.

The top horizontal scale allows the progress of transformation at the axes of oil-quenched bars (r/b*$= 0$) to be assessed, and the subsidiary scales allow assessment of the progress of transformation at the mid-radius ($r/b = 0{\cdot}5$) and near-surface ($r/b = 0{\cdot}8$) bar positions. These three scales were derived from the data already published by the authors,[6] although the derivation of the scales for the $r/b = 0{\cdot}5$ and $0{\cdot}8$ bar positions involved some extrapolation and minor corrections were necessary to allow for the slightly different cooling conditions prevailing in the dilatometer cooling chamber.

The diagrams actually apply only to the particular severity of oil-quenching used in the derivation of the correlation between air- and oil-cooling. This quench was of an average type, neither very severe nor very mild, and the effect on the diagram of varying the quenching intensity within the range likely to be encountered in practice would probably be much less than that caused by cast to cast composition differences. The horizontal scales on the diagrams could, however, be modified to relate the diagrams to a significantly different severity of oil-quench, if sufficient cooling curves were available to allow the derivation of the appropriate relationship between air-cooled and oil-quenched bars.

* r = distance from axis, b = radius of bar

The following examples will serve to illustrate the interpretation of the diagrams. Figure 7 shows that if a 2-in. dia. bar of the B.S. En 12 steel is quenched in oil from 845° C. the axis of the bar will start to transform when it reaches 585° C.; it will have transformed 50% at 530° C. and completely at 400° C. The near-surface material ($r/b = 0{\cdot}8$) of the same bar will start to transform when it reaches 580° C., will have transformed 50% at 515° C., and will finish transforming at 380° C.

Fully martensitic structures will be developed at the axes of only very small bars of the En 12 steel—probably less than $\frac{1}{2}$-in. dia.—and sections in excess of about $1\frac{1}{2}$-in. dia. will develop no martensite at the axis. The diagram for the En 23 steel (Fig. 11) shows that this more highly alloyed steel will harden fully at the axis when oil-quenched in sizes up to about $3\frac{3}{4}$-in. dia. and that 6-in. dia. bars will develop nearly 50% of martensite at the axis.

The dilatation tests on one of the two En 26 steels (steel F) showed that this steel would transform wholly to martensite when oil-quenched in sizes up to nearly 6-in. dia., the dilatation curve corresponding to a 6-in. dia. bar quenched in oil showing only traces of transformation to products other than martensite. The continuous-cooling diagram for this particular sample of B.S. En 26 steel, which would of course

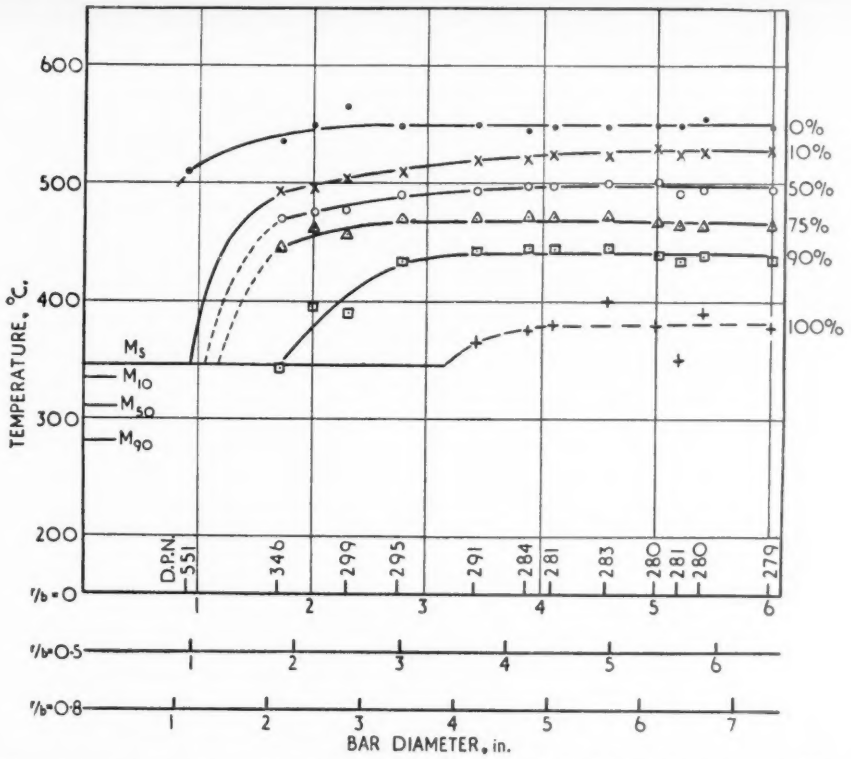


Fig. 8—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 16 steel, austenitized at 845° C.

show little more than the martensite reaction lines, has not been reproduced. The other sample of B.S. En 26 (steel G) had lower hardenability, presumably due to its lower carbon content; its diagram is given in Fig. 12.

The types of structure developed at different temperatures are not shown on the diagrams, although this is an addition that might profitably be made in the future. Nevertheless, from experience with isothermal transformation diagrams, it is not usually difficult to differentiate between pearlite and bainite formation on continuous-cooling transformation diagrams. The diagrams for the shallower hardening steels (*e.g.*, B.S. En 12 and 111) show two distinct ranges within which transformation proceeds predominantly to bainite or to ferrite and pearlite structures. These regions are linked by a range within which these transformations overlap and the percentage transformation lines, particularly the 90% and 100% lines, rise steeply with increase of bar diameter.

The majority of the deeper-hardening steels do not form ferrite/pearlite structures when oil-quenched in sizes up to 6-in. dia. and consequently their diagrams display only a bainite shelf, the upper temperature limit of which appears to approach, with increase of bar diameter, the upper limit of the corresponding shelf on the isothermal transformation diagram.

The diagrams for the B.S. En 17 and 111 steels show the M_s temperature decreasing slightly as the section size increases above the critical diameter for complete transformation to martensite. This is believed to be due to the prior separation of upper bainite increasing the carbon content of the residual austenite, which later transforms to martensite. A similar effect has been noted by Cameron.[10]

The hardness values along the bottom edge of the diagrams are those of the dilatometer samples after cooling to room temperature; they provide an indication of the values to be expected at the positions and in the sizes of bars indicated by the horizontal scales.

The transformation lines on the continuous-cooling diagrams have not been extended below the M_s temperature to meet the corresponding martensite transformation lines. The progress of transformation below the M_s temperature was readily followed by the dilatometric method, but the rates of cooling of the dilatometer test specimens probably diverge rapidly from those of the equivalent sizes of oil-quenched bar below about 300° C., and consequently the time-dependent portion of the transformation could not be regarded as being representative of the behaviour of an oil-quenched bar. Nevertheless, the dilatation tests were continued down to almost room temperature, and examples of an increase in transformation rate at or just below the M_s temperature were noted. For example, the dilatation test bar corresponding to a 6-in. dia. bar of B.S. En 26 (steel F) quenched in oil transformed so rapidly at its M_s temperature that the fall of temperature due to air-cooling was almost

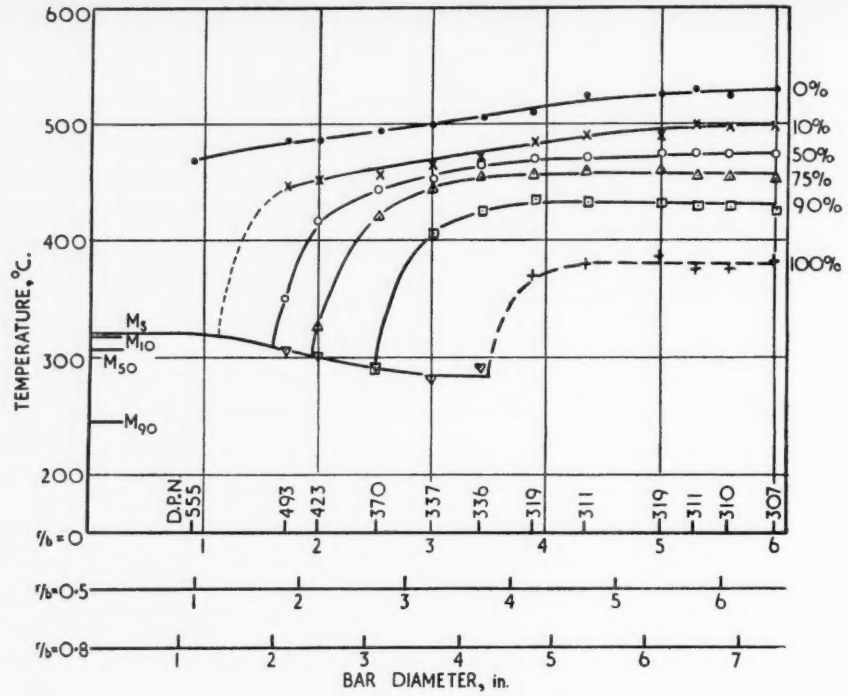


Fig. 9—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 17 steel, austenitized at 845° C.

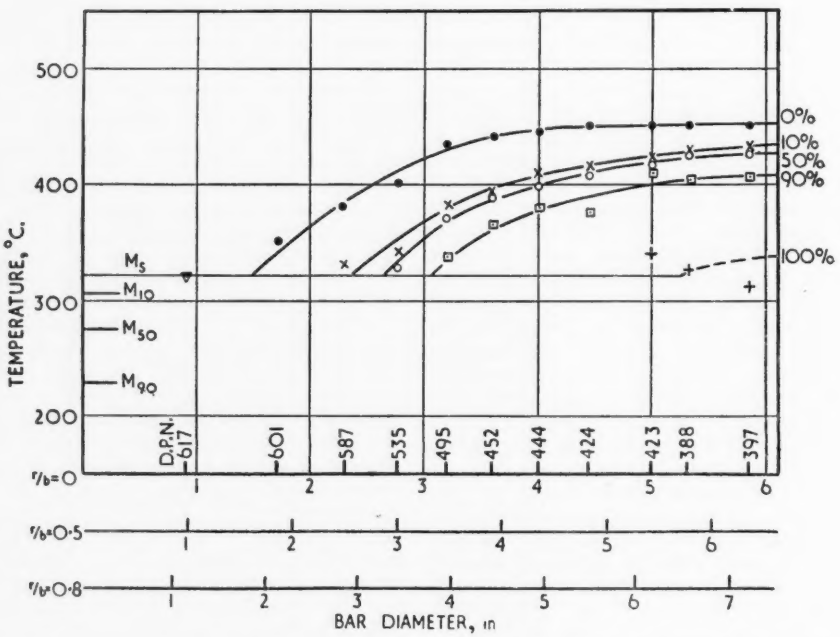


Fig. 10—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 19 steel, austenitized at 850° C.

completely arrested by the heat of transformation, and transformation was almost complete when the temperature again started to fall.

The structures and hardness values of oil-quenched bars of two of the steels were compared with those to be expected from the continuous-cooling diagrams.

A 2·8-in. dia. bar and a 1·7-in. dia. bar were machined from a 3-in. square billet of the En 12 steel and oil-quenched under the standard conditions. The microstructure at the axis of the larger bar consisted

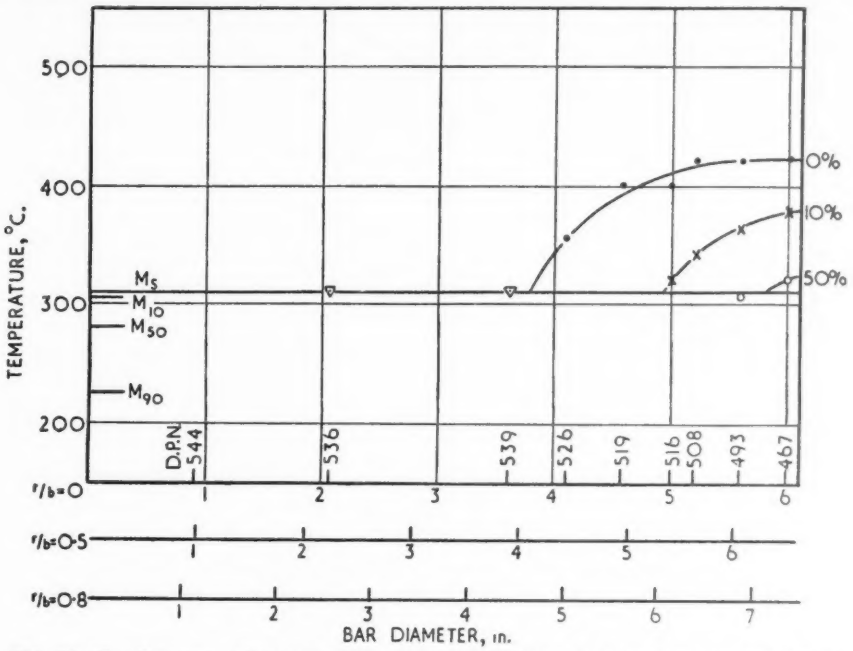


Fig. 11—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 23 steel, austenitized at 835° C.

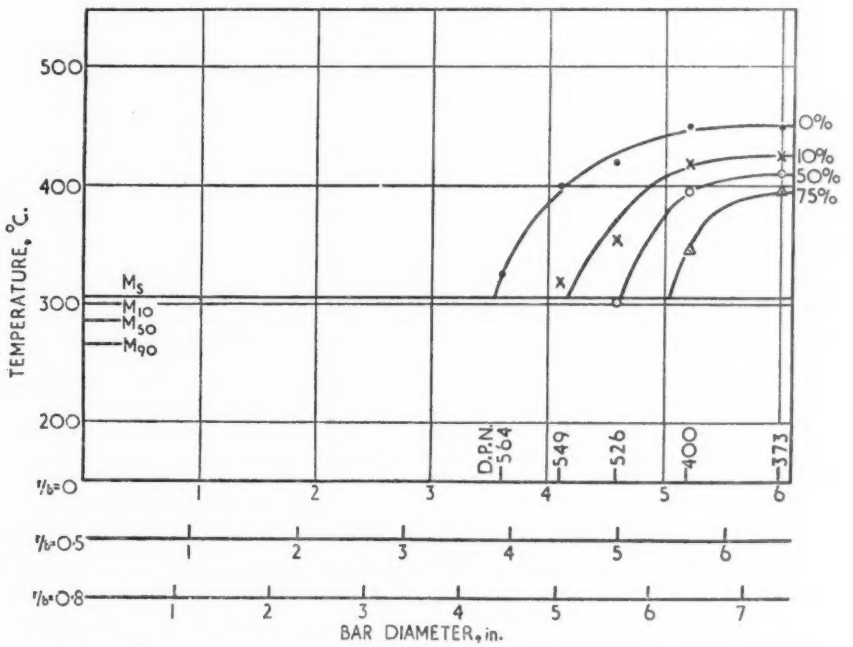


Fig. 12—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 26 (steel G), austenitized at 835° C.

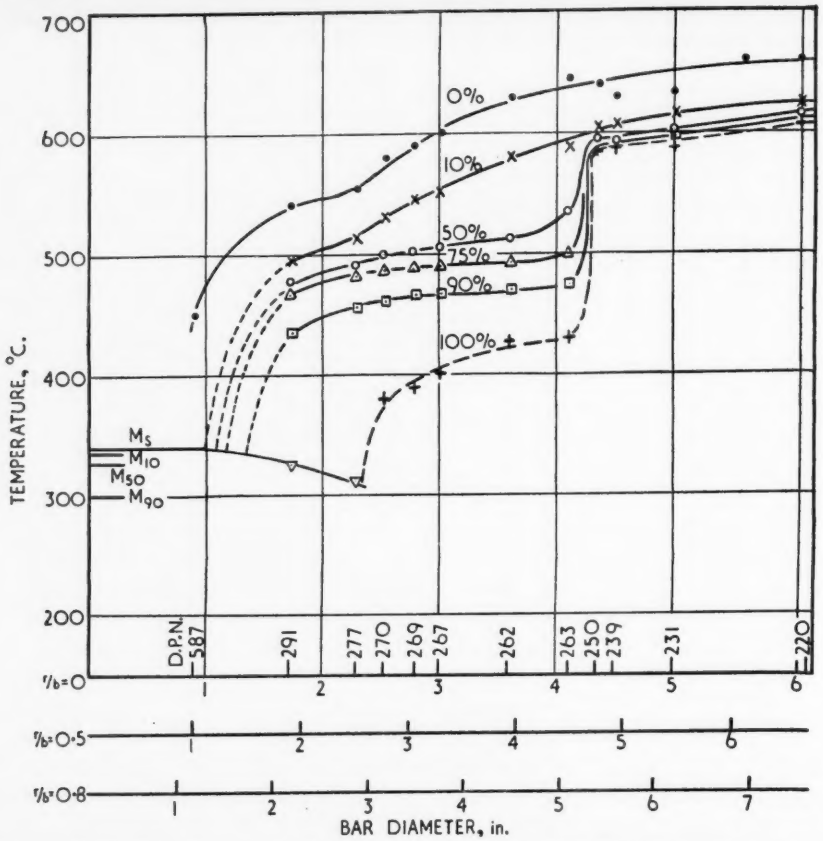


Fig. 13—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 111 steel, austenitized at 845° C.

of grain boundary ferrite and pearlite, and the microstructure of the corresponding air-cooled dilatometer specimen was similar but somewhat finer. The microstructure at the axis of the 1·7-in. dia. bar showed two distinct types of structure, zones of ferrite and pearlite occupying 50–55% of the section, and zones of upper bainite in martensite occupying the remainder (Fig. 6*a*). The corresponding dilatometer specimen had a much more uniform structure, consisting of intermediate bainite with 3–4% of fine pearlite nodules (Fig. 6*b*). The differences between these two structures can be accounted for by the greater uniformity of the material used for the dilatometer specimen. The latter was machined from a $\frac{3}{8}$-in. dia. hot-rolled bar, whereas the oil-quenched bar had been machined from a billet that had been hot-rolled to only 3-in. square. As the 1·7-in. dia. bar is near a critical diameter, the local differences in alloy content due to residual dendritic segregation have been clearly reflected in the structure of the oil-quenched bar.

Although the microstructures of the 1·7-in. dia. oil-quenched bar and of the equivalent air-cooled dilatometer specimen differed appreciably, their hardness values and those of the 2·8-in. dia. oil-quenched bar and its equivalent dilatometer specimen were in close accord (Fig. 4*a*).

A 3·4-in. dia. bar and a 1·7-in. dia. bar of the En 17 steel machined from $3\frac{1}{2}$-in. and $2\frac{1}{2}$-in. square billets respectively were oil-quenched to allow a similar comparison to be made for this steel. The structure of the larger oil-quenched bar contained 60–65% of upper bainite, the remainder being lower bainite. The structure of the corresponding dilatometer specimen contained 85% of intermediate bainite together with lower bainite. The 1·7-in. dia. oil-quenched bar contained 20% of intermediate bainite, and the balance was lower bainite and martensite. The corresponding dilatometer bar contained 30% of intermediate bainite, the balance being lower bainite and martensite. The structures of both the dilatometer specimens were distinctly finer than those of the oil-quenched bars. However, the structural differences between the oil-quenched bars and the dilatometer specimens could be caused by the greater homogeneity of the smaller bars from which the specimens were machined.

The hardness values for the axes of the oil-quenched bars of the En 17 steel were in fair accord with those of the corresponding dilatometer bars (Fig. 4*c*).

The results of these tests on the En 12 and 17 steels serve to emphasize that continuous-cooling diagrams, like isothermal diagrams and end-quench hardenability curves, cannot be used for exact forecasts—particularly in the vicinity of critical diameters—unless precautions are taken to ensure that the material used to determine the diagram is wholly

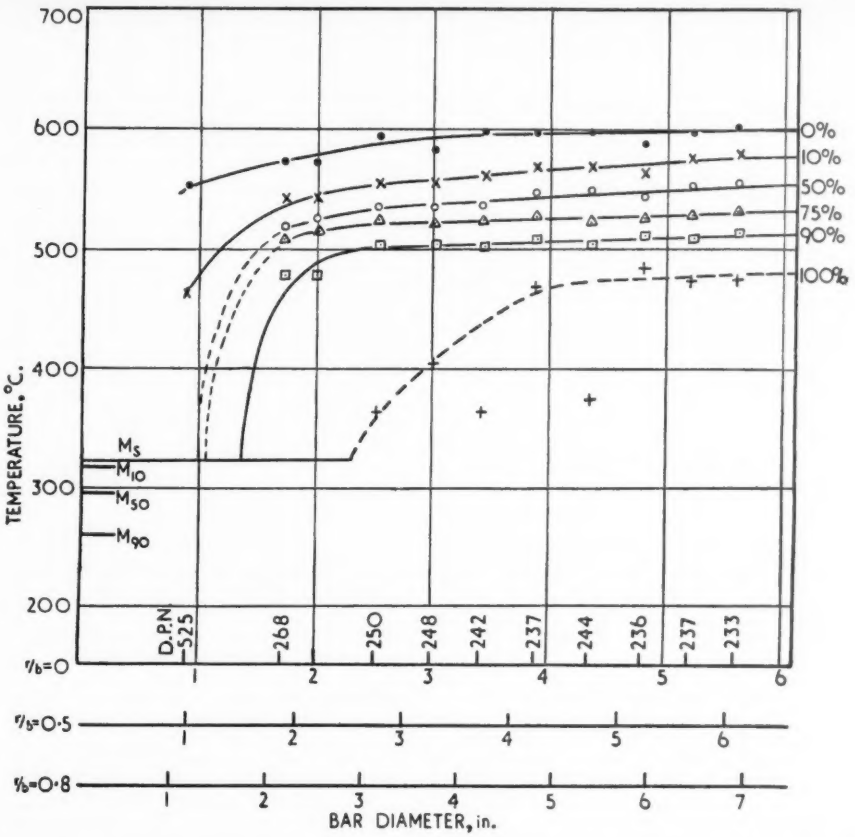


Fig. 14—Continuous-cooling transformation diagram for O.Q. bars of the B.S. En 160 steel, austenitized at 845° C.

representative of the material to be treated. A greater degree of correlation could be achieved by determining the continuous-cooling transformation characteristics of 1–6-in. dia. bars using dilatometer specimens machined from bars hot-rolled to these sizes. The amount of machining involved would, however, be prohibitive, and even this procedure would not allow account to be taken of the variation of transformation characteristics within a cast and between different casts of the same type of steel. The effects of inhomogeneity will be important only near the critical diameters, and over the greater range of bar sizes the diagrams will indicate—with an accuracy that is adequate for most purposes—the behaviour to be expected from a steel. Comparison of the continuous-cooling diagrams for the two samples of B.S. En 26 steel examined indicates that appreciable differences can exist between the transformation characteristics of different casts of the same type of steel.

COMPARISON OF CONTINUOUS-COOLING AND ISOTHERMAL TRANSFORMATION DIAGRAMS

It is well established that longitudinal and transverse variations of hardenability exist within billets and bars of commercially satisfactory steel.[13] These variations must, of course, be reflections of variations of isothermal transformation characteristics, and consequently the isothermal transformation characteristics of a billet of steel cannot be exactly represented by a single diagram. As a result, it has become general practice in this country to determine isothermal transformation diagrams using specimens machined from wire or tape, hot-rolled and cold-drawn from billets, so that the full cross-section is represented in the test-sample. It is clear, however, that individual parts of billets and bars will generally possess slightly different transformation characteristics from those portrayed by the diagram obtained from samples machined from wire or, indeed, from any other type of sample.

In view of the above considerations, it was not surprising that tests demonstrated that differences existed between the transformation characteristics of the wire samples used to determine the isothermal transformation diagrams previously published and the rod samples used in this work to determine continuous-cooling diagrams. The rod samples were produced from the same billets as the wire samples, but they were from different parts of the billets and were hot-rolled to a lesser extent; they were not cold-drawn and were finally machined to a proportionally greater extent. Each isothermal diagram and each continuous-cooling diagram portrays transformation characteristics within the ranges represented in the

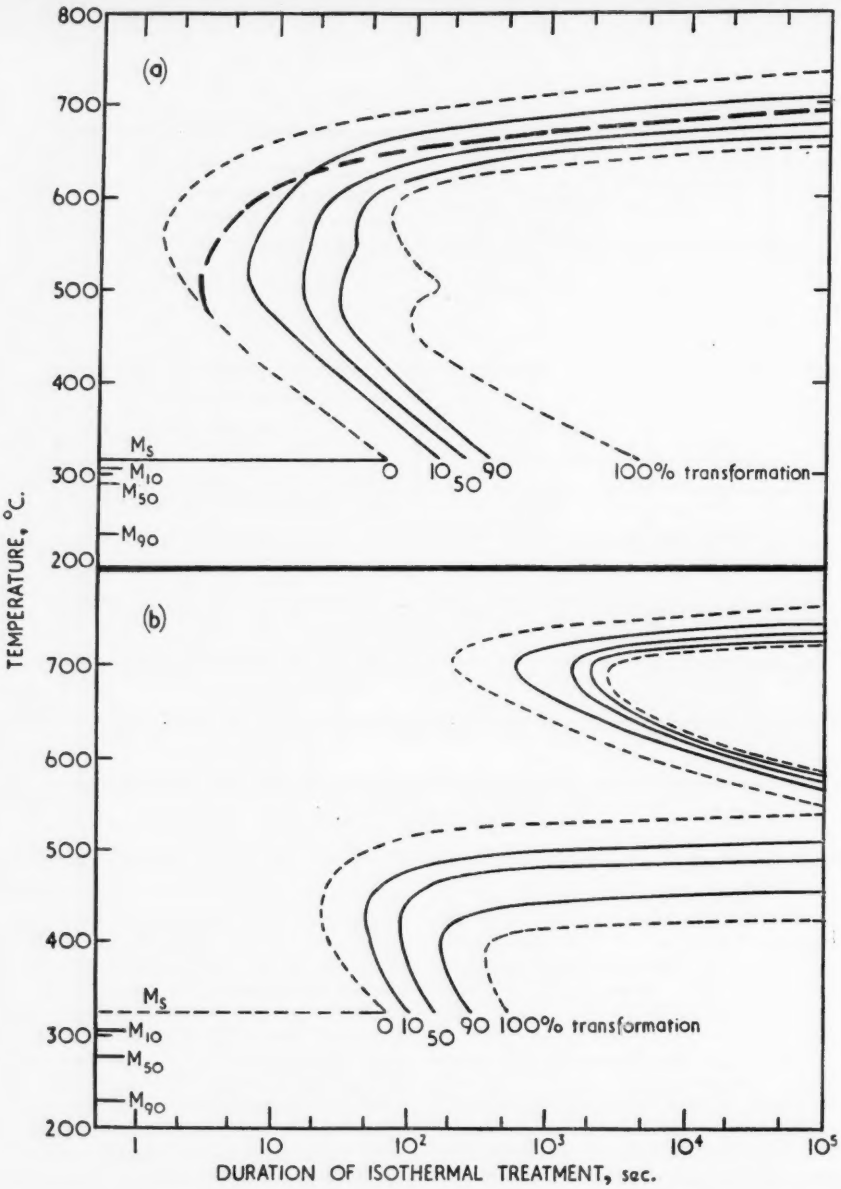


Fig. 15—Isothermal transformation diagrams for (*a*) the B.S. En 12 steel, austenitized at 845° C., and (*b*) the B.S. En 19 steel, austenitized at 850° C.

casts, but the pairs of diagrams are not comparable to the close degree required for a precise comparison of continuous-cooling and isothermal transformation characteristics. The diagrams for the B.S. En 12 and 19 steels shown in Figs. 15*a* and *b*, which were determined using samples machined from the mid-radius position of $\frac{5}{8}$-in. dia. rod (which was one of the intermediate bar sizes used to determine the continuous-cooling diagrams), can, however, be accepted as being closely representative of the isothermal transformation characteristics of the samples of those steels used in the investigation. The conclusions reached below regarding the relationship between continuous-cooling and isothermal transformations are consequently based on comparisons of the relevant diagrams for these two steels only.

The isothermal transformation diagrams for the B.S. En 12 and 19 steels were used to calculate the temperatures at which transformation would be expected to start under continuous-cooling conditions, on the basis of the Scheil hypothesis,[11] but assuming, as recommended by Manning and Lorig,[2] that time

spent in the pearlite range does not contribute to nucleation of transformation in the bainite range. The temperatures derived were on average 15°–20° C. higher than those indicated by the continuous-cooling diagrams, and the Scheil factors at the temperatures at which transformation actually started varied from the hypothetical value of 1 to as high as 2·7 (Table IV). The possible effects of experimental errors in both the continuous-cooling and isothermal diagrams are such that these discrepancies cannot be considered to be significant. The present work was not planned to assess closely the accuracy of the Scheil hypothesis, and a more detailed study is required.

An attempt was next made to forecast from the isothermal transformation diagrams the subsequent progress of transformation, using the procedure described by Pumphrey and Jones,[12] which involves assessing the start of transformation by the Scheil method. Discrepancies were revealed between the derived data and the data that were observed experimentally. Although, according to the calculations, transformation started 15–20° C. earlier than was indicated by experimental observations, the subsequent progress of transformation according to the calculations was very much slower than that observed experimentally, and the derived temperatures for 50, 90, and 100% transformation were markedly low. Also, within certain ranges of cooling rate the calculations indicated transformation to be incomplete at the M_s temperature, whereas full transformation had been observed experimentally. It is probable that these differences between calculated and actual progress of transformation with temperature are due in part to the arrest in cooling rate which occurs during transformation. This is not taken into account in the method of calculation that has been tried.

COMPARISON OF END-QUENCH HARDENABILITY CURVES AND CONTINUOUS-COOLING TRANSFORMATION DIAGRAMS

The relative hardenabilities of the steels as indicated by the continuous-cooling transformation diagrams were in accord with those indicated by the end-quench curves of Fig. 1.

The hardness values to be expected at the axes of oil-quenched bars were derived from the end-quench hardenability curves of several of the steels, using the correlation between hardenability curves and hardness traverse curves suggested by the authors.[6] These hardness values are compared with those of the dilatometer samples in Fig. 4.

In general, the values derived from the end-quench hardenability curves suggested that the steels possessed greater hardenability than did the hardness values of the dilatometer samples. This, of course, was not unexpected, as the end-quench hardenability curve reflects the hardenability of the material near the surface, and it has been demonstrated[13] that the latter is frequently greater than the hardenability of the core material of which the dilatometer specimens were more representative.

This explanation was confirmed by additional tests on the En 17 and 160 steels. A hardenability curve was determined for the axial material of a 2½-in. dia. bar of the En 17 steel, and the hardness values for oil-quenched bars derived from this curve, as shown in Figure 4*c*, were in good accord with those of the dilatometer specimens. Hardness values derived from the hardenability curve for the axis of a 4-in. dia. bar of the En 160 steel were also in much closer agreement with those of the dilatometer samples than were the hardness values derived from the curve determined on the specimen machined from a 1⅛-in. dia. bar (Fig. 4*f*).

Table IV

CALCULATED AND OBSERVED START OF TRANSFORMATION TEMPERATURES

Steel	O.Q. Bar Diameter, in.	Start of Transformation, °C.		Scheil Factor at Start of Transformation
		Experimental	Calculated	
B.S. En 12 (Steel A)	5¾	645	660	2·3
	3¾	630	645	2·1
	3	618	635	2·1
	2	585	620	2·7
B.S. En 19 (Steel D)	5¾	450	475	1·9
	3¾	445	445/450	1·0
	3	420	435	1·3
	2	365	385	1·15

Acknowledgments

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The Water-Cooling of Open-Hearth Furnaces

By A. M. Frankau, M.A.

SYNOPSIS

A series of measurements has been made on a number of open-hearth furnaces of the flow rate and temperature rise of the cooling water supplied to the individual cooling units. The heat losses imposed by these units are an important factor in furnace operation, as it has been shown from these trials that they can involve a high proportion of the heat input. It is calculated that the required heat input for a given heat loss is in the ratio of 1·8 : 1 for oil firing and 2·1 : 1 for producer-gas firing.

Trials on a tilting furnace during a single campaign showed that the measured heat loss rose from 11·4% to 15·7% of the total heat input. This increase was due to severe erosion of the refractory covering the cooling units in the port ends.

The largest heat losses occurred in units such as furnace chills and door frames, where there were surfaces unprotected by refractory and subject to direct radiation or gas impingement. It is therefore recommended that every effort should be made to ensure adequate covering of the cooling units wherever possible. 753

It is reasonable to suppose that the heat loss incurred by water-cooling various parts of an open-hearth furnace has often been measured by works technologists and that, as a matter of routine, care is taken to keep these losses under observation and as low as possible.

At the same time, the trials described in the paper suggest that water-cooling losses are still a major item in the heat balance of an open-hearth furnace, and that finality has not yet been reached in efforts to reduce these to a minimum. Water-cooling as such is not necessarily detrimental to the furnace; when certain vital parts of the brickwork are protected in this way, more heat can be concentrated in the bath area, which may give greater production for a lower heat consumption per ton of product. It is more important to reduce direct heat losses to the cooling water than to reduce water-cooling.

Although the loss of heat to cooling water is the main problem, the supply and pumping of the water involved is also very important. For example, on several of the furnaces on which measurements were taken, more than 36 tons of water were circulated for every ton of steel produced. In the range of temperatures normally used, the quantity of water flowing does not affect the heat losses, but it can have a considerable effect on the supply, pumping, and circulating costs.

WATER-COOLING UNITS

Water-cooling is applied to open-hearth furnaces to protect refractories, to cool sliding surfaces, and to cool structural supports.

The cooling pipes fitted in gas ports are a good example of the direct use of water-cooling to protect refractories. These pipes may be placed on the end of the nose of the port and covered by a thin layer of chrome paste. In practice, although they soon become partly exposed owing to the refractory falling away, they prevent serious erosion of the port and subsequent lack of control of the flame. In arranging cooling units on a furnace, a balance is struck between the cost of heat being carried away continually in the cooling water and the cost of having the furnace out of production for repairs. Cooling units may therefore be used to ensure that major parts of the furnace have about the same life.

The chief use of water-cooled door frames is to protect the door jambs and door arches from damage from badly filled charging boxes and the charging machine. Incidental advantages are the considerable protection afforded to the buck-stays against the effects of heat, and the better air seal obtained with the door by preventing burning and warping. On tilting furnaces, the chills at the rotating joints are cooled to provide a reasonable sealing face against air infiltration and flame escape.

Skewback channels, buck-stays and other structural steelwork are occasionally cooled to prevent distortion when the brickwork covering them wears thin. Units such as back-wall coolers are fitted to improve the working conditions of the furnacemen during tapping. These units are faced with thick brickwork and

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Mr. Frankau is on the staff of the Plant Engineering Division of the Association.

Table I

HEAT LOSS THROUGH COOLED AND UNCOOLED WALLS

Brick Thickness, in.	Heat Loss (Uncooled Wall), B.Th.U./sq. ft./hr.	Heat Loss (Cooled Wall), B.Th.U./sq. ft. hr.	Increase in Heat Loss due to Cooling, %
18	1200	1500	25
9	2200	2800	27
4½	4100	5400	32
2	8100	11,900	47
1	14,100	23,000	63

probably carry away little more heat than would be lost from these surfaces with no coolers.

The quantity of water needed for circulation depends more on the quality of the water used than on the temperature rise between inlet and outlet. The velocity, and hence the quantity required, is determined by the amount of sediment carried in the system, as the flow rate must be such as to prevent it settling out. The danger from this sedimentation is that it may cause local overheating and failure of the metal, owing to the internal insulation effect. For economy, it is preferable to maintain the largest temperature rise possible, the upper limit being set by the rate of scale deposition from the water; this is usually taken as 160° F., since above this temperature calcium-carbonate scale is formed.[1] There can be wide fluctuations in temperature rise from any cooling unit, depending on furnace conditions, and so the highest likely to be reached should be used as one criterion for adjusting flow rates.

HEAT LOSSES

The methods of calculating heat losses through refractory brickwork are well known, but it is of interest to compare the losses that occur through various thicknesses of externally water-cooled and uncooled walls. This information has been calculated for various thicknesses of refractory from 18 in. to 1 in., and is given in Table I. The furnace temperature has been taken as 1650° C. and the thermal conductivity of the brick as 0·7 B.Th.U./sq. ft./° F./ft./hr. It has been assumed that in the cooled case the water is at 100° F., and in the uncooled case that the external atmosphere is at 60° F. These figures are arbitrary and are intended only to show the variations that are caused by the condition of the brickwork.

Table I shows that the heat loss from a water-cooling unit depends on the thickness of brickwork. A fully exposed water-cooled surface can extract 196,000 B.Th.U./sq. ft./hr., so that it is very important to keep an adequate covering of refractory over all cooling units. It is not justifiable to assume that a unit that is external to a furnace wall will not extract more heat than would be lost through an uncooled wall; unless the refractory is very thick, there will be an increased temperature gradient through the wall and an increased heat flow. A proportion of the heat passing to the cooling water of doors and frames probably comes from the 'sting' of flame that is often seen to be emitted; it is sometimes argued that this heat would be lost to the atmosphere in any case. With a tight-fitting door, however, there should be no heat loss.

Water-cooling is not necessarily detrimental to furnace performance, but considerable losses can and do occur if the cooling units are not adequately protected.

FURNACE TRIALS

Estimates have been made of the heat lost to the cooling water on a number of furnaces by measuring the individual rates of flow in each part of the system and continuously recording the rise of temperature through each cooling unit. Where possible, observations have covered complete tap-to-tap cycles, thus including all stages of a melt—fettling, charging, refining, and tapping.

Records of calorific and sensible heat input to the furnaces over the same periods were obtained from the fuel flowmeters installed at the works.

Measurement of Temperature Rise and Water Flow-Rate

The individual outlet temperatures of each cooling unit and the common inlet temperature were measured by means of copper–constantan thermocouples connected to a high-speed 44-point temperature recorder.[2] These recordings allowed the temperature rises through the various units to be calculated. The rate of recording was about one cycle of the 44 thermocouples in each minute.

The water flow-rates were either measured by deflection of the outlet for a given time into a large calibrated vessel, or by means of rotating-vane water meters fitted into branch lines from the cooling units. These meters had a tendency to choke with debris carried round by the water, and a close watch had to be kept on them during a measurement. In one instance, as a check, orifice plates were fitted in the main supply pipes to a furnace, and agreement within 3% was found between the total flow and the summation of the various separate units.

Table II

TOTAL HEAT LOSSES

Furnace	Tons Tapped	Steel Production, tons/hr.	Water Flow, gal./hr.	Heat Loss, therms/hr.	Heat Loss, therms/ton	Heat Input, therms/hr.	Heat Loss as Percentage of Heat Input
Fixed 1	85	6·7	16,764	50·88	7·6	425·7	12·0
„ 2	75	5·9	28,260	109·23	18·5	396·4	27·6
„ 3	75	7·6	49,470	67·36	8·9	368·7	18·3
Tilting 4	309	10·5	63,650	77·89	7·4	693·4	11·4
„	320	11·5	63,739	72·97	6·4	572·7	12·7
„	187	8·2	66,748	104·23	12·7	659·2	15·7

The rates of liquid fuel and atomizing steam flow or gas flow were taken from the usual furnace instruments and corrected to give both sensible and calorific heat input over the period of each trial.

Total Heat Losses Compared

The furnace trials covered random periods during the campaigns of three furnaces at three different works using basic fixed furnaces, and three periods during one campaign of a basic tilting furnace at a fourth works. As a basis for comparing the different furnaces, the water-cooling losses have been given as a percentage of the appropriate heat input. Table II gives a summary of the data obtained, but items such as therms per ton, although of interest for an individual furnace, should not be compared, since they are dependent on many variables, such as the percentage of hot metal used in the process, the length of refining period necessary, etc.

Table II shows that the heat losses can reach much higher values than are generally appreciated, the maximum recorded being 27·6% of the heat input, which is equivalent to over 2500 therms/day, *i.e.*, about 1400 gal. of fuel oil or 10 tons of gas-producer coal each day.

Fixed Furnaces

Table III gives a summary of the water-cooling losses from the three fixed furnaces.

The furnace in the first trial was of the venturi type, and was fired with a mixture of blast-furnace and coke-oven gas. The second furnace was also of the venturi type, but was fired with steam-atomized oil fuel. Its door frames were of the ' archless ' type, *i.e.*, they had an additional cooled projecting ledge at the lintel to provide arch support. This almost certainly accounts for the increased heat losses from these units compared with the previous furnace. The largest contribution to the considerable heat losses from this furnace was from the tunnel coolers.

The third furnace tested was similar to the second, but was fired with a 50/50 mixture of tar and pitch creosote. In this case, even for an older furnace, the heat losses were much smaller. This might be due to a possible difference in furnace pressure, which would cause flame and hot gases to lick round the unprotected door frames and tunnel coolers of the second furnace.

In all the trials, as would be expected, the losses from the doors and door frames were greatest for those at the centre of the furnace, and diminished towards the ends. The biggest heat losses seem to be caused by the door frames. The differences between these losses from the three trials are probably due mainly to the variations in design and the corresponding surface areas that are subject to direct radiation from the furnace. The fuel used in firing the furnaces may also be expected to have some effect.

Figure 1*a* shows the variation of temperature rise for one of the tunnel coolers for the period of the trial on the second furnace. This shows the large swings that can occur on reversal (in this case 41° F.), particularly from such exposed surfaces as these. The fluctuation of the cooling-water temperature in the centre door and door frame for the same trial on the second furnace is given in Fig. 1*b*. This shows the variations due to the state of operation of the furnace; the fluctuations due to reversals are small for a cooling unit in this position. These maximum temperatures

Table III

FIXED-FURNACE HEAT LOSSES

Furnace No. and Age, weeks	Situation and No. of Cooling Units	Water Flow, gal./hr.	Average Temperature Rise, ° F.	Heat Losses		
				Therms/hr.	% of Total Heat Loss	% of Total Heat Input
No. 1 (6)	Doors (5)	2802	45·6	12·78	25·1	3·0
	Door frames (5)	10,584	25·0	26·51	52·0	6·2
	Gas port coolers (10)	3378	34·3	11·59	22·9	2·8
	Total	16,764	30·4	50·88	100·0	12·0
No. 2 (7)	Doors (5)	8988	21·9	19·72	18·1	5·0
	Door frames (5)	9312	60·4	56·26	51·4	14·2
	Oil burner and tunnel coolers (4)	8892	36·6	32·56	29·9	8·2
	Back-wall coolers (2)	1068	6·5	0·69	0·6	0·2
	Total	28,260	38·7	109·23	100·0	27·6
No. 3 (16)	Doors (5)	14,622	11·9	17·42	25·8	4·7
	Door frames (5)	23,892	18·6	44·40	65·9	12·1
	Oil burner and tunnel coolers (4)	8196	6·1	5·04	7·5	1·4
	Back-wall coolers (2)	2760	1·8	0·50	0·8	0·1
	Total	49,470	13·6	67·36	100·0	18·3

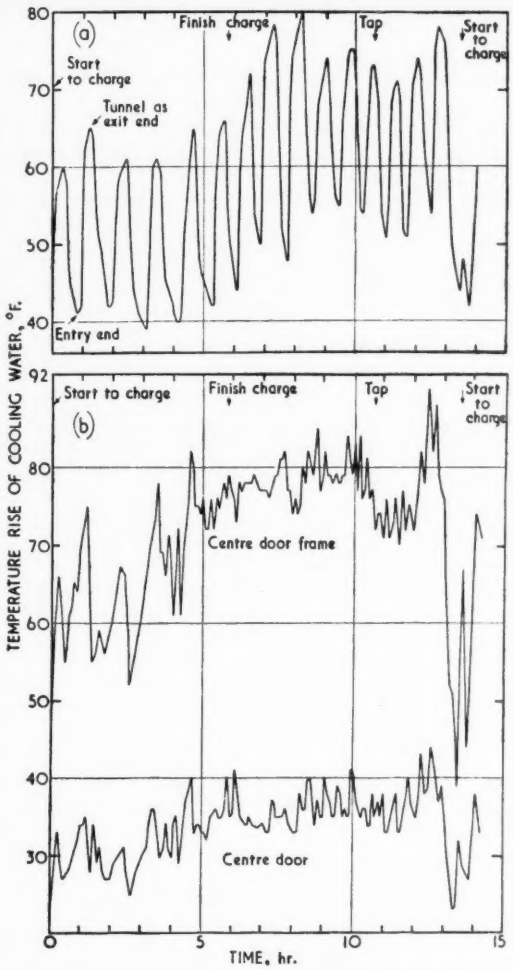


Fig. 1—Temperature/time relation for (*a*) tunnel cooler and (*b*) doors and door frames

must be known for any particular unit, since any setting of the water flow-rate must bring this into consideration. A random reading should not be relied on for this purpose.

Tilting Furnace

The trials on the tilting furnace, which was producer-gas fired, were carried out during the first, seventh, and sixteenth weeks of operation during a single campaign. Table IV summarizes the heat losses during these periods.

Two major auxiliaries were installed during this campaign—an additional gas producer, which came into operation between the first and second trials and increased the available supply of gas to the furnace and the sensible heat at the gas downcomer, and a waste-heat boiler, which was installed between the second and third trials and improved the control over the draught to the chimney. At the time of the third trial, there was a shortage of raw materials, and so only small charges were put into the furnace.

There were 58 individual cooling units on this furnace, mostly situated in the port ends. Each port end had, as coolers, six pipes round the top of the nose of the gas port, nine 'torpedo' pipes along the top of the gas port, a hollow water-cooled frame (the 'back stopping door'), a plate cooler in the end wall, and a water seal at the gas and air uptakes.

The heat losses from the doors could only be recorded during the first trial owing to difficulties of measurement; since there was no great variation in heat loss from the door frames during the three trials, however, it is reasonable to assume that there would be little in the doors themselves. In the closed position, protection was given by both the door frame and a high bank of dolomite on the sill.

Table IV shows that the cooling-unit losses fall into two distinct groups—those in which there is an increasing heat loss during the life of the furnace (port-end units), and those in which there is little or no increase (door frames and chills).

Since it was a large-capacity tilting furnace, the door frames were behind a large thickness of refractory, which almost certainly accounted for the very small losses compared with the previous trials and for the lack of variation throughout the campaign.

The chills accounted for over one-third of the total heat losses and are an example of the effect of having completely unprotected metal surfaces exposed to the furnace heat. The total area facing into the furnace was about 40 sq. ft., which gave a loss of about 1 therm/sq. ft./hr. of exposed surface. This was only the heat loss as measured by the rise in temperature of the cooling water and does not include any direct loss through the chills, which in this case consisted of heavy steel castings with a cast-in cooling pipe.

The increase in heat loss with age of the furnace occurred in the port-end units where there was considerable erosion of the refractory surrounding them. After 16 weeks, these were in many places subject to direct radiation and gas impingement.

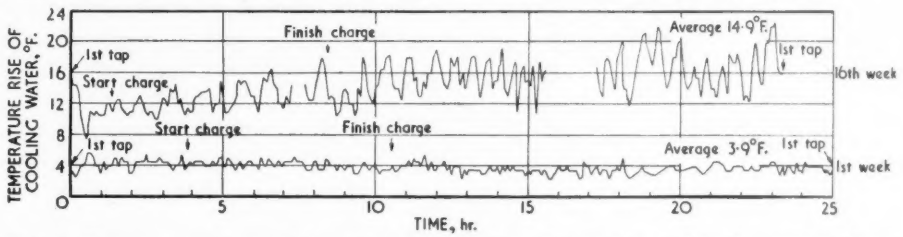


Fig. 2—Temperature/time relation for torpedo pipes, flat cooler, and back stopping door (1st and 16th weeks)

Table IV

TILTING-FURNACE HEAT LOSSES

Time of Trial	Situation and No. of Cooling Units	Water Flow, gal./hr.	Average Temperature Rise, °F.	Heat Losses		
				Therms/hr.	% of Total Heat Loss	% of Total Heat Input
1st week (*A*)	Doors (5)	3984	14·2	5·68	...	0·8
	Door frames (5)	5640	24·4	13·79	17·7	2·1
	Chills (12)	27,095	14·4	39·08	50·2	5·6
	Gas port coolers (34)	28,890	6·4	18·47	23·7	2·8
	Water seals (2)	2025	32·3	6·55	8·4	0·9
	Total (excluding doors)	63,650	12·2	77·89	100·0	11·4
7th week (*B*)	Door frames (5)	4805	35·0	16·81	23·0	2·9
	Chills (12)	31,556	10·4	32·66	44·8	5·6
	Gas port coolers (34)	25,959	7·2	18·62	25·5	3·4
	Water seals (2)	1419	34·4	4·88	6·7	0·8
	Total	63,739	11·4	72·97	100·0	12·7
16th week (*C*)	Door frames (5)	3865	42·2	16·34	15·7	2·5
	Chills (12)	31,735	11·6	36·86	35·3	5·5
	Gas port coolers (34)	27,132	13·2	35·73	34·3	3·1
	Water seals (2)	3746	40·8	15·30	14·7	2·3
	Total	66,478	15·7	104·23	100·0	15·7

An example of this increase in heat loss with age is given in Fig. 2. This is a plot of the variation of temperature rise at 5-min. intervals during the first and sixteenth weeks of operation for the trials of the torpedo pipes, back stopping door, and plate cooler at one end of the furnace. The water flow-rates for the first and last trials were 5190 and 5490 gal./hr., and the average temperature rises were 3·9° and 14·9° F. respectively. The heat loss rose from 2·02 to 8·18 therms/hr. and, even with the slightly reduced heat input of the third trial, this represents an increase of over 400%. The cyclical variations due to furnace reversals are clearly indicated, and the large increase in both swing and mean temperature is a direct result of the erosion of the protecting refractory.

DISCUSSION OF RESULTS

So far, only the heat losses as measured by the increase in temperature of the cooling water through the various units have been considered. But it is important to try to assess what these losses actually mean. There are two aspects of this problem; firstly, what heat loss is caused by a water-cooling unit additional to that normally lost through the brickwork of the furnace, at the location of the cooling units, and secondly, what additional heat input is required to compensate for this extra loss.

If the door frames of a furnace are considered, it is fairly easy to determine the additional heat losses they cause and, for the four furnaces considered in this paper, these losses are set out in Table V.

The surface areas of the frames that are in contact with the furnace walls have been determined approximately from the relevant drawings, and 1500 B.Th.U./sq. ft./hr. (*see* Table I) has been taken as the loss that would occur without water cooling. This is very small in comparison with the measured loss. The assumptions made here are that the heat losses from the working chamber in the absence of water-cooling would only be through brickwork, and that water-

Table V

DOOR-FRAME HEAT LOSSES CAUSED BY WATER COOLING

Furnace	Surface Area of Each Frame in Contact with Furnace, sq. ft.	Estimated Loss Without Water Cooling, therms/hr.	Measured Heat Loss, therms/hr.	Loss Caused by Water Cooling, therms/hr.	Area of Exposed Surface of Each Frame, sq. ft.	Loss per sq. ft., therms/hr.
1	23	1·72	26·51	24·79	4	1·24
2	14½	1·09	56·26	55·17	11¼	0·98
3	14½	1·09	44·40	43·31	11¼	0·77
4*B*	15¼	1·14	16·81	15·67	3⅛	0·89

Table VI

DOOR-FRAME HEAT LOSSES—REQUIRED HEAT INPUT

Furnace	Measured % of Total Heat Input	Heat Loss by Water-Cooling, therms/hr.	Input Fuel	Input/Loss Ratio	Required Heat Input, therms/hr.	Percentage of Total Heat Input
1	6·2	24·79	Blast-furnace and coke-oven gas*	2·3	57·02	13·4
2	14·2	55·17	Oil	1·8	99·31	25·1
3	12·1	43·31	Tar and creosote-pitch	1·8	77·96	21·1
4*B*	2·9	15·67	Producer gas	2·1	32·91	5·7

* Ratio of gases ≃ 1:2

cooling units are not used to fill in gaps in the furnace body where the brickwork is rapidly eroded away.

This difference in heat loss is composed of only a small increase in heat loss through the wall due to the effect of cooling the surface of it, and the major portion must be caused by direct radiation to the surfaces of the frames that are exposed to radiation from the furnace chamber. If all the increase is taken as being due to this factor, it can be seen from Table V that for every square foot of exposed surface area there is a corresponding increase in heat loss of about 1 therm/hr.

As the working chamber does not operate as a 100% efficient heat exchanger, an additional loss of heat from the body of the furnace calls for an increase of fuel input in excess of the heat loss. As shown in the Appendix, this increase is in the ratio of 1·8:1 for oil firing and 2·1:1 for producer-gas firing. This ratio only holds for losses of usable heat from the working chamber; for any cooling unit outside its boundaries, *i.e.*, for the gas ports and uptakes, the figures will be only half the above if an efficiency of 50% is taken for the regenerators.

Thus, for the door frames, as considered in Table V, a new assessment of the heat losses as a percentage of the heat input can be made, and these are given in Table VI, which shows what the real effect of unprotected units, in terms of heat input, can be.

Similar figures can be given for the other cooling units on the furnaces, and the results are summarized in Table VII.

CONCLUSIONS

The results of these trials clearly indicate that the heat lost by cooling water is an important factor in furnace operation, and the major cause of heat losses was found to be lack of adequate refractory protection of the cooling units. Losses as high as 27½% of the heat input were recorded, which represents an additional heat input of over 40% necessitated by the cooling units.

Table VII

TOTAL HEAT LOSSES—REQUIRED HEAT INPUT

Furnace	Measured % of Total Heat Input	Heat Loss by Water-Cooling, therms/hr.	Required Heat Input, therms/hr.	Percentage of Total Heat Input
1	12·0	50·88	103·70	24·4
2	27·6	109·23	164·91	41·6
3	18·3	67·36	116·71	31·7
4*B*	12·7	72·97	128·57	22·4

The quantities of water used are necessarily large because of scaling and deposition problems, and this makes the temperature rise through the units small. Design of cooling units to take advantage of larger temperature rises with reduced water flow would effect a saving in pumping and supply costs.

For fixed furnaces, about 50% of the total heat losses are accounted for by the door frames, the maximum value recorded for a single unit being 14·5 therms/hr. at a flow-rate of 1866 gal./hr. and a temperature rise of 76·9° F.

The trials on the tilting furnace showed that unprotected units, such as chills, can be responsible for very large heat losses. The variations of heat loss with furnace life, as would be expected, occur in those units where the refractory life is great enough to expose the cooling units towards the end of a campaign.

It has been shown by calculation that 1 in. of refractory protection over a water-cooled surface can reduce the losses per hour from 196,000 to 23,000 B.Th.U./sq. ft. This provides evidence of the large losses that occur through exposed cooling units and of the importance of ensuring refractory protection at all times.

The required heat input for a given heat loss from the furnace chamber is shown to be in the ratio of 1·8:1 for oil firing and 2·1:1 for producer-gas firing. This means that any measured heat losses can be increased by at least one-half to give the heat input required.

It should not be thought, however, that water-cooling is an unnecessary evil in an open-hearth furnace. Water-cooling can and does play an important part in increasing the life of vulnerable parts of the furnace, and possibly allows harder driving. But these losses cannot be ignored, and every effort should be made to reduce them where possible.

Many units, such as chills and the inside surfaces of door frames, are never protected in any way, and it is suggested that the use of high-magnesia ramming mixes on a welded stud foundation would help to give some protection. This type of plastic mix is extensively used in America for door linings, and excellent results are reported.[3]

Acknowledgments

The author acknowledges with thanks the kindness and co-operation that he received from members of the staff at the various works where these trials were carried out. He is also indebted to Mr. A. J. Blanchard for his help with the recording of the experimental data.

APPENDIX

The Fuel Input Necessary to Maintain a Heat Loss in a Furnace

By A. L. Cude, B.Sc., A.M.I.Chem.E.

Figure 3 represents an open-hearth furnace and shows the principal heat distribution. The symbols, which all refer to heat transferred in unit time, are :

h_s	Heat transferred to steel
h_L	Heat loss from working chamber
H_A	Heat transferred in working chamber
H_F	Heat in fuel
H_R	Heat returned as air preheat
H_L	Heat loss from regenerators, ports and uptakes
H_s	Heat in stack gases.

Heat Loss from the Working Chamber

Taking heat balances over the working chamber,

$$H_A = h_L + h_s \quad \ldots\ldots(1)$$

$$H_A = (H_F + H_R) - (H_s + H_L + H_R)$$
$$= H_F - (H_s + H_L) \quad \ldots\ldots(2)$$

If the regenerator efficiency is denoted by e,

$$e = \frac{H_R}{H_s + H_L + H_R}$$

and

$$1 - e = \frac{H_s + H_L}{H_s + H_L + H_R} \quad \ldots\ldots(3)$$

The quantity $(H_s + H_L + H_R)$ represents the total heat in the gas leaving the chamber, and its value will depend on the quantity of gas and its temperature. Since for a definite air/fuel ratio the quantity of gas is proportional to the fuel input, it is possible to put

$$(H_s + H_L + H_R) = a.H_F$$

where a is a factor depending on the kind of fuel, the excess air ratio, and the exit temperature of the furnace gas. Then, from equation (3),

$$H_s + H_L = (1 - e).a.H_F \quad \ldots\ldots(4)$$

and, from equation (2),

$$H_A = H_F - (1 - e).a.H_F$$
$$= H_F[1 - a(1 - e)]$$
$$\text{or } H_A = b.H_F \quad \ldots\ldots(5)$$
$$\text{where } b = [1 - a(1 - e)]$$

From equation (1),

$$h_L + h_s = b.H_F \quad \ldots\ldots(6)$$

Assuming that the rate of heat input to the steel remains constant, equation (6) can be differentiated to give

$$\frac{d(H_F)}{d(h_L)} = \frac{1}{b}$$

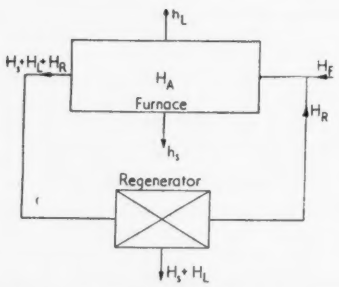


Fig. 3—Diagram of heat distribution in an open-hearth furnace

This means that if the heat losses from the working chamber are reduced by an amount Δh_L, the fuel input must be reduced by an amount $\Delta h_L/b$ to maintain the same exit gas temperatures and heat transfer to the steel.

Value of b

The coefficient b is given by $b = [1 - a(1 - e)]$, where a is the ratio of the heat content of the waste gases leaving the chamber to the heat input in the fuel, and e is the regenerator efficiency.

Assuming an exit-gas temperature from the working chamber of 1700° C., and 20% excess air, Rosin's data[4] allow the value of a to be found for various fuels as follows:

Fuel	Net Calorific Value	a
Oil	17,000 B.Th.U./lb.	0·88
Creosote–pitch	16,000 ,, ,,	0·88
Coke-oven gas	500 B.Th.U./cu. ft.	0·94
Producer gas	160 ,, ,,	1·06
Blast-furnace gas	99 ,, ,,	1·36

It is possible for a to have a value greater than 1 because it is the ratio of the heat leaving the chamber to that in the fuel only, and not the total heat entering the chamber. A value greater than 1 indicates that the required exit temperature can only be reached if the combustion air is preheated.

The value of the regenerator efficiency e is usually about 0·5, so that values of b can be found for the various fuels. The heat loss must be multiplied by $1/b$ to give the equivalent fuel consumption ; $1/b$ is as follows:

Fuel	$1/b$
Oil	1·8
Creosote–pitch	1·8
Coke-oven gas	1·9
Producer gas	2·1
Blast-furnace gas	3·1

Heat Loss from the Ports and Uptakes

Reducing heat loss from the ports and uptakes will increase the sensible heat content of the waste gas entering the regenerators, but this extra heat can only be returned to the working chamber through its effect on the air preheat. If the saving in heat loss is ΔH_L, the quantity of heat returned to the furnace is $e\Delta H_L$. This additional quantity of heat will have the same effect on fuel consumption as stopping an equal heat loss from the working chamber, so that the reduction in fuel input is given by

$$\Delta H_F = \frac{e\Delta H}{b}.$$

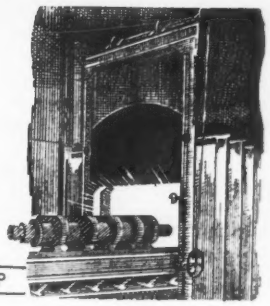
In the open-hearth furnace, where e is about 0·5, a reduction of heat losses from the ports and uptakes will give only half the fuel saving resulting from the reduction of a direct loss from the furnace chamber.

References

1. " Corrosion of Iron and Steel by Industrial Waters and Its Prevention," Spec. Rep. No. 41, p. 33: 1949, London, The Iron and Steel Institute.
2. R. T. FOWLER: *Instrument Practice*, 1952, vol. 6, pp. 233–241.
3. " Iron and Steel—Productivity Team Report ", p. 71: 1952, London, Anglo-American Council on Productivity.
4. P. O. ROSIN: " Waste Heat Recovery from Industrial Furnaces," pp. 6–37: 1948, London, Chapman and Hall (for the Institute of Fuel).

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE TWENTIETH MEETING

THE TWENTIETH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Thursday, 11th December, 1952. Mr. C. H. T. WILLIAMS (The Park Gate Iron and Steel Co., Ltd.), Chairman of the Group, was in the Chair.

The MORNING SESSION was occupied by the presentation and discussion of three papers on heat recovery.

The AFTERNOON SESSION was devoted to the presentation and discussion of the paper "Some Factors Affecting the Operation and Performance of Open-Hearth Furnaces," by D. F. MARSHALL (The Park Gate Iron and Steel Co., Ltd.).

PROCEEDINGS OF THE AFTERNOON SESSION: 2 P.M. to 4.15 P.M.

Discussion on the Paper—

SOME FACTORS AFFECTING THE OPERATION AND PERFORMANCE OF OPEN-HEARTH FURNACES*

Dr. **D. F. Marshall** (Park Gate Iron and Steel Co., Ltd.), in introducing his paper, drew attention to the following error:

Page 321, Table III: Under 'E' furnace with the No. 1-type chequer filling, the fuel used in gal./ton should read 29·4 and not 39·4 as printed.

Dr. **A. H. Leckie** (B.I.S.R.A.): I agree with most of what the author says, so that my arguments must be based more on details than on broad principles.

The author mentions all the disadvantages of producer gas without mentioning its chief advantage, that of cost. He shows that in this country 29–39% of the operating cost is due to fuel, which is the reason why fuel costs are so important. Therefore, as a therm of producer gas still costs appreciably less than a therm of liquid fuel, the economic gain from oil must be entirely due to any increased output that it gives. In a works where the furnace capacity is well matched to the mill capacity, so that maximum furnace output, irrespective of ingot costs, need not be sought, I wonder whether the author's arguments still apply. One of the chief arguments which he put forward was that for a given heat input waste-gas volumes are much less with oil and rich fuels than with producer gas, but I feel that in practice the difference is not quite so marked, because in any furnace there is always a large 'ballasting' volume of infiltrated air in the waste gas, so that differences brought about by the character of the fuel are considerably less than theory would indicate.

I agree that an old melting shop with limited checkers and small or non-existent slag pockets could not operate at anything like the present rates on anything but a rich fuel, but I do not think that this should be taken to mean that oil would have corresponding advantages over producer gas everywhere. I wonder whether the managements concerned with some of the latest producer-gas shops would agree that conversion to oil would give them additional output that would compensate for the extra cost of the oil. If I were a melting-shop manager concerned principally with output and ease of operation and control, I should want liquid fuel or coke-oven gas, but if I had to keep an eye on costs I should want to be completely convinced that a modern producer-gas layout with automatic control would not be more economic from the point of view of overall works cost of the finished product.

The author mentions the question of steam/oil ratio. I do not question his statement that in some of his furnaces he got increased production when the steam was raised to 9 lb./gal., but is it not extraordinary that he needs to put nearly a ton of water-vapour into his furnace every hour to keep it hot enough? He gives the reason as being to get enough velocity in the nozzle, and states that unless well-superheated steam is used these high quantities of steam are necessary. I would emphasize the need for superheated steam, because

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 315–326.

adequate superheat seems to be lacking in so many of our works. The position with regard to steam/oil ratio can be eased by using central uptakes, for instance, but ensuring plenty of dry steam will help to reduce high steam consumption.

I find Fig. 1 especially interesting, as it gives some of the data that we in B.I.S.R.A. really want to help us in our study of metallurgical load. One point invites question. In periods 4 and 5, the total pig iron—hot and cold—went down, but the slag bulk went up. Was the mixer failing, or was there something peculiar about the iron analysis ?

In Table II very interesting figures are given showing the relationship between metallurgical load and tons per hour. I should like to see the regression line connecting silicon in lb. per ton with tons per hour, as distinct from just the correlation coefficient, as this would provide an interesting comparison with the figures given by Jackson,* where it seems that the slope of the line connecting silicon with tons per hour is quite steep.

The author mentions the desirability of pretreating the metal in some way before the open hearth. Good though mixers are, there may be cheaper ways of doing it, and this is another case where the help of the engineers will be badly needed. Most of the pretreating schemes that I have studied require for their success some method of separating slag and metal. The engineers might like to make a study of how slag and metal can be separated simply and efficiently, without trouble from skulls, slag incrustations, and maintenance difficulties.

Regarding furnace size, Fig. 3*a* is perhaps more important than Fig. 3*b*, as the author says, but Fig. 3*b* is completely influenced by the fact that bigger furnaces give more tons per hour; any other effect is rather masked by that. It is interesting that the line in Fig. 3*b* goes almost through the origin. The author mentions a figure of 0·069 tons/hr. per ton increase in tapping capacity. I think that the slope of the line would rather suggest 0·08 tons/hr., but that is a point of detail. I wonder where he gets his figure of 0·027 tons/hr. for each ton of added tapping capacity for British hot-metal furnaces. If he gets it from the B.I.S.R.A. collected data, did he include the tilting furnaces, which have a completely different slope ? I had another look at the British fixed furnaces and it seemed to me that the slope was about parallel with the American ones, but at about 1 ton/hr. lower productivity.

The author admits some statistical limitations in Fig. 3*a*, but, whatever the professional statisticians think about it, it does emphasize the fuel gain from larger furnaces. The very low figures of fuel consumption which we all admire at Abbey are not entirely the result of something magical, but are largely contributed to by the large size of the furnaces. When they are plotted on the extension of the British diagram, they are shown to be good, but not outstandingly out of line. This furnace size influences fuel consumption substantially. The difficulty which we face in this country is that the structure of the industry is such that many works have still to deal with a wide diversity of orders, so that they cannot use big furnaces, with their large amounts of delivered metal of constant analysis, to quite the same extent as can American works, where the variety of orders is probably much less.

The last point in connection with fuel is that nearly everyone emphasizes over and over again the familiar fact that the fuel per ton goes down as the tons per hour go up. This may be true, but it is an illustration of the fact that furnaces are not operating at the optimum capacity, perhaps owing to difficulties of one kind or another in combustion or to overheating the roof. When a fast-working furnace is being driven at its maximum production rate, there may well be a position where the gallons per ton start to creep up as the maximum production rate is reached, due to the 'peak' of the characteristic curve being passed. It is a pity that for reasons of easy statistical calculation the lines connecting tons per hour and fuel are often drawn straight, because if the furnaces are running at anything like peak capacity the true relationship may be appreciably curved.

In regard to design, the author's conclusions on bath depth are presumably based on some form of multiple correlation taking out the effect of capacity, but there is bound to be some confusion on this point of the influence of bath area per ton on production. We all feel, I think, that a large hearth area per ton is desirable, but we also generally find that, when we deepen the bottom or build up the banks and so get more steel into the furnace, we get more tons per hour; and some new shops which started with 150-ton furnaces are already putting more into them than they originally envisaged. When designing new plant, 5 sq. ft./ton may be the original intention, but when more steel is put in and the hearth area per ton is reduced more tons per hour will be obtained. Such progress can continue up to the limit of the crane capacity. I have yet to hear of a furnace being overloaded so much that the actual tons per hour go down. It would be interesting to hear of any case where the optimum loading of the furnace has been passed.

At past meetings I have often talked about single uptakes. Although the advantages of the single central uptake for oil-fired furnaces up to 100 tons capacity are undisputed, a school of thought seems to be growing up—and I suspect that the author belongs to it—which believes that single uptakes are of no use in larger furnaces. These views may be based on the disappointing performances of some large furnaces when converted to single uptakes. In a small furnace, one of the chief advantages of the single uptake is its ability to secure rapid and early mixing of fuel and air. In a large furnace, with the necessary distance between the end of the doghouse-type burner and the bath, the single uptake may not give this advantage, and, in fact, if a single uptake is put into a very big furnace the resulting early combustion may overheat the incoming end, with insufficient heat left in the flame at the outgoing end. I still think, however, that, provided one is careful about the design, and the single uptake is not made too big nor placed too far from the bath, the single uptake is just as right for the large furnace as for the small. There may not be much better combustion than with the doghouse design, but a single uptake is simpler and cheaper and gives a better flow pattern, so that refractory wear should be less. When there is bad refractory wear with the single uptake, it is a symptom of some fault in the furnace itself, which could probably be rectified, and not a fault in the principle of the single uptake.

Very little seems to be known about what is needed in the way of checkers, largely because any theoretical calculations one may do are vitiated by the change in shape and slag deposits on the checker bricks as time goes on. We all agree that height is the most important factor, and the American figure of 15 ft. agrees well with our own conception of a minimum of 20 ft. from the centre line of the bottom flue to the centre line of the top flue. Although two-pass checkers should give very good distribution, the extra twists and turns must mean extra pressure drop, particularly when choking with slag begins to take place. I am told that there have been difficulties with cracks in dividing walls, and also that there is a tendency for short-circuiting to take place within the two-pass system.

* A. Jackson, *J. Iron Steel Inst.*, 1949, vol. 162, pp. 160–162.

The remarks on American methods of increasing furnace availability are very valuable, but it should be known that there is at least one works in this country which, so far as I can see, is beating the Americans. At Corby the furnace first tap is made regularly about 18½ hr. after the last bricklayer is out.

I agree with the author's remarks on furnace control. Fast charging and fast melting go together, and in order to charge quickly the flame and combustion conditions must allow quick melting. It may be that in some of our newest plants the bottleneck is simply the rate at which the charge can absorb the heat presented to it, so that even more attention must in future be paid to matters such as flame temperature and emissivity, which affect heat transfer.

I am not clear about the real meaning of Fig. 7. With the range of bath length given in Fig. 7, it is obvious that we are not dealing with the same size of furnace throughout, so that, as the author himself said, the effect of the size of the furnace more than anything else is shown here. The analysis of O.H. furnace data shows most clearly how difficult it is to separate out the effect of size and to get the true effect of some of the other factors.

The author has demonstrated very clearly that Britain seems to have some lead over America in the application of automatic control. He emphasizes that American methods of control still tend to be governed more on pressure than on a volume measurement, and that is a real weakness. I still feel that engineers tend to place too much reliance on pure pressure measurement when flows are being considered, because, although in most engineering applications pressure and flow are strongly related, in the O.H. furnace the size of the passages and orifices concerned changes so much that the pressure/flow relationship is not always connected in the way that one would expect, so that it is preferable to base control measurements on volume.

It is a great pity that O.H. furnaces cannot be made sufficiently air-tight to benefit fully from air/fuel ratio control. The trouble is, of course, that there is inevitable infiltration at doors, even when the incoming and outgoing system is tight. Many shops are still at fault in the way that ill-fitting doors are left incompletely seated and spy-holes are left open. Engineers should be able to make a door that will stay reasonably gas-tight in the rough conditions of the O.H. furnace.

Although air/fuel ratio control would be an advantage, I think that the constant-air theory is valid for many of our furnaces today. This constant-air level should be set at slightly more than the theoretical air for the maximum fuel rate, which means that during charging and the early stages of melting, when the fuel is the maximum that the furnace will burn, there is extra air to take care of the air absorbed in oxidizing the iron. Later, when the roof is up to temperature, the fuel drops below the maximum and the excess air that arises from keeping on the original air flow will tend to cool the roof and allow the maximum heat transfer to the hearth without overheating the roof. The fact that this happens was fairly well proved on one of the models on which we experimented. The flow-pattern work that is going on may develop a design where there is no risk of overheating the roof, even with the absence of this air protection, and then it will be possible to ratio the air to the fuel without the risk of burning the roof, and accordingly to save fuel.

Mr. G. R. Bashforth (Round Oak Steel Works, Ltd.): I think that one reason why in this country the average results with producer-gas-fired furnaces, as compared with some of the oil-fired furnaces, are not better is

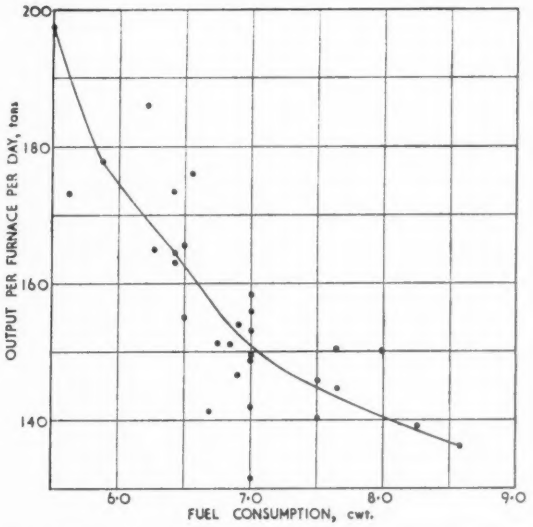


Fig. A—Effect of productivity on fuel consumption

that in most cases the introduction of oil-firing was coincident with the introduction of furnace instrumentation, which permitted more rigid control of operational conditions. There is no doubt that the adoption of a greater degree of instrumentation would improve the results that are now being obtained on many producer-gas-fired furnaces. When the benefits and advantages to be obtained from oil as compared with producer gas are considered, the factors which have brought about that increased productivity and reduced fuel consumption might be analysed.

As the author has pointed out, the properties of the two fuels lead us to expect a very much lower waste-gas volume and therefore a lower loss of heat from that source. Unfortunately, however, the sulphur content of the British oils is higher than that of the American oils, and it is frequently necessary, when making low-sulphur steels, to work with a very high air/fuel ratio in order to reduce the sulphur pick-up. That tends to diminish the saving that might otherwise result.

Another economy factor is the higher flame temperature that can be developed with oil fuels as compared with producer gas; this enables cold stock to be melted-down quickly. The advantages from this high flame temperature and rapid melting can be obtained only if charging facilities that permit rapid charging are available. That is perhaps the reason why there are such varying results in fuel consumption in the different plants of this country where oil has been adopted, in some of which adequate charging facilities and facilities in the pitside for disposing of the products are not available.

Fuel may also be saved during the reversal period of a regenerative oil-fired furnace. On very large furnaces with frequent reversal—say every 10 or 15 min.—there is a big loss of gas on each reversal, which may amount to from 40,000 to 50,000 B.Th.U. per ton of ingots. All these advantages must be borne in mind when considering the advantages of the two fuels.

I agree that there is a definite relationship between the rate of productivity and the fuel consumption; we find, however, that for our own plant there is a good deal of scatter due to other causes; this is shown in Fig. *A*. As the slag volume increases, so does the fuel consumption. The introduction of coke, owing to the

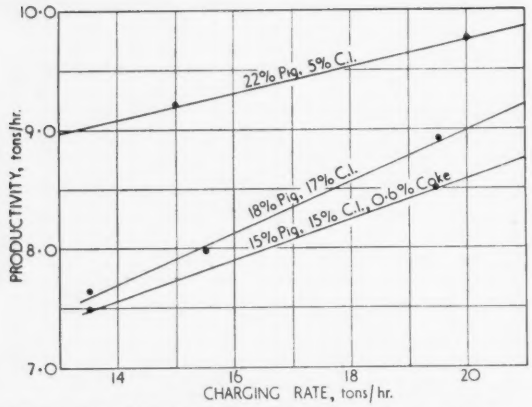


Fig. B—Relationship between productivity and charging rate for varying percentages of pig iron

shortage of pig iron, also increases the fuel requirements. The slag volume or the metallurgical load not only affects the fuel consumption but also materially affects the rate of productivity, as will be seen from Fig. *B*. This graph gives the effect of the charging rate on the rate of productivity, showing that there is a definite depressing of the rate of productivity as a result of varying metallurgical load.

Perhaps one reason why our efficiency or productivity is lower in this country is that there are many old-fashioned plants, operating on producer gas, where instruments have not been adopted and where we have not perhaps fully appreciated the fundamental factors affecting the operation of our own furnaces. In starting up the new plant at Round Oak, we have had many problems which we have tried to tackle in a systematic and statistical manner. For example, one feature that we feel is of supreme importance is the uptake pressure, shown in Fig. *C*. We find that there is an optimum uptake pressure at 0·8–0·85 in. W.G., after which there is a definite falling off. This is probably due to restriction caused by growth in the chrome-magnesite port, so that the necessary heat input is not obtained, but we were getting satisfactory rates of productivity up to the point shown. This rate, of course, includes the time for fettling.

A very systematic examination of our furnace practice was therefore made by two methods, one of which has already been discussed by Dr. Walker at the Cleveland Institute of Engineers in December, 1951.* By means of 'pie' diagrams (Fig. *D*) we examined the charging, melting, refining, and fettling times, and found a progressive improvement. It will be noted that during the last period the capacity had increased to 107·7 tons/cast, which improved the rate of productivity, but the advantage of this increased capacity was to some extent off-set by a deterioration in the quality of the steel scrap, which fell to a bulk density of 51·7 lb./cu. ft., as compared with 73·5 lb./cu. ft. in 1951.

Examining these improvements, we find that there are several factors that have affected the rate of productivity. I shall not discuss such things as the bulk density of scrap nor the charging rate, which Dr. Walker has already discussed, but I would mention the effect of the sooting period. One disadvantage of producer gas that the author has mentioned is sooting-up and the need to clean out the mains. Our plant is designed so that each furnace circuit can be isolated for the purpose of burning out the mains. During the early period of operation, the practice was to let the furnaces run until the gas supply was definitely restricted and then to burn-out the mains, which generally took a considerable time. Now this burning-out is done every nine or ten days, with the result that we lose on an average only two hours per furnace per week.

Perhaps one of the most important factors in the increased rate of productivity has been the reduction in the melting time. There has been an improvement in the rate at which we have been able to cut down our cold stock, which we attribute to the size of the gas ports, and it is closely linked with the uptake pressure. We think that the uptake pressure influences the velocity that can be imparted to the gas flame at the ports and that this is fundamental to the speed with which we can melt. Originally the gas port had an area of 5 sq. ft. and, assuming that the gas entered at 1000° C., the velocity at the port would be about 85 ft./sec. To obtain a greater velocity, we decided to close-in the ports, giving an area of 3·7 sq. ft. and a velocity of 115 ft./sec. This modification had been completed on all furnaces by the end of May 1951, and we consider that this feature largely contributed to the increased rate of productivity shown for that period in Fig. *E*.

It was decided to further reduce the port area to 2·9 sq. ft. by raising the sole of the gas port 3 in., thereby giving a velocity at the port of 144 ft./sec. This alteration was completed on all furnaces except *B* by the end of February 1952, and a further improvement resulted, as shown in Fig. *E*. The decreased productivity shown on *B* furnace during this period is attributed to water-cooling troubles resulting from an electrical failure. It seems that high gas velocities at the port are of great importance on producer-gas-fired O.H. furnaces in ensuring the rapid cutting-down of cold stock.

The further increase in the productivity rate shown for the last period in Fig. *E* is largely attributed to the increased furnace capacity, the average weight per cast having increased to 107·2 tons, compared with 96·9, 97·0, and 99·9 tons/cast respectively for the previous periods.

The author has made a very important point on furnace availability. When this is considered, I think that three factors should be studied: (i) the correct scheduling or planning of repairs, which to a great extent depends on the expectation of furnace life; (ii) the speed with which repairs can be done; and (iii) the preheating period before making steel after the completion of the repairs.

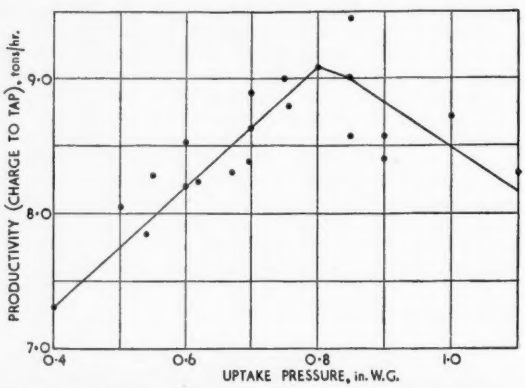


Fig. C—Effect of uptake pressures on rate of productivity

* W. S. Walker, Spec. Rep. No. 48, pp. 17–23: 1953. London, The Iron and Steel Institute.

The scheduling of repairs is of fundamental importance and should be one of the chief functions of melting-shop management. In making his schedule of repairs, the melting-shop manager must rely upon his records to ascertain the expectation of life, which is very largely influenced by the correct selection of refractories to obtain maximum life, and upon ensuring that the suppliers maintain the right quality. At the same time, he must not overlook the possibilities of improving furnace life by better refractories or modification in furnace design. We are at present scheduling on a 32-weeks' campaign, with an intermediate repair to the roof and ports at the end of 16 weeks. The repairs are very largely governed by the life of the roof, and we have experienced a very vulnerable spot along the back-wall about 5 ft. either side of the taphole. A few months ago, however, we made a slight structural alteration, which consisted of leaving three openings, 6-in. × 4½-in., in the back-wall immediately underneath the roof. The object was to permit a slight infiltration of air to prevent the eddying current that had been responsible for the erosion of the roof at this point. These openings are immediately over the taphole and 5 ft. either side of that point. From the results obtained to date, it would appear that this modification may extend the roof life by three or four weeks.

The speed with which repairs can be executed depends on good organization and the degree of mechanization. We have recently completed a repair in 9 days, 1 hr. and 35 min., but we think that with increased mechanization we can considerably improve on this figure.

Our original preheating practice was a 33-hr. period, but recently we have reduced that time to 24 hr. I think the most important range to watch is between 200° and 300° C., when the alpha to beta cristobalite change is taking place. Provided that the roof is brought through this range at not more than 12° C./hr., there should be no danger of spalling. The furnace is normally tapping within 36 hr. after gassing. Recent experience on our larger furnaces, on which we can take far more liberties than on our old 60-ton furnaces, suggests that the American furnaces can be preheated more quickly because of their size. Perhaps the reserve of heat in these larger furnaces, which is bigger than in the smaller ones, enables the brickwork to absorb heat gradually, so that the changes during the preheating period are not so drastic.

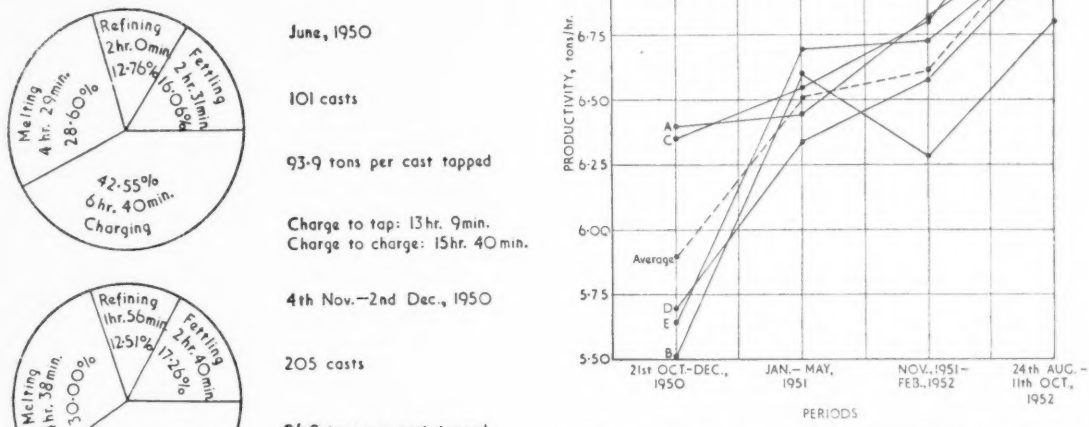

Refining 2hr. 0min. 12·76%
Fettling 2 hr. 31min. 16·06%
Melting 4 hr. 29min. 28·60%
42·55% 6 hr. 40min. Charging
June, 1950
101 casts
93·9 tons per cast tapped
Charge to tap: 13 hr. 9min.
Charge to charge: 15hr. 40 min.
Refining 1hr. 56min. 12·51%
Fettling 2hr. 40min. 17·26%
Melting 4hr. 38min. 30·00%
40·13% 6hr. 12 min. Charging
4th Nov.—2nd Dec., 1950
205 casts
96·9 tons per cast tapped
Charge to tap: 12hr. 47min.
Charge to charge: 15hr. 27 min.
Refining 1hr. 37min. 11·54%
Fettling 2hr. 8min. 15·24%
Melting 3hr. 55min. 28·00%
45·23% 6hr. 20min. Charging
17th Feb.—24th March, 1951
275 casts
97·0 tons per cast tapped
Charge to tap: 11hr. 52min.
Charge to charge: 14 hr.
Refining 1hr. 28min. 10·29%
Melting 4hr. 3min. 28·42%
Fettling 1hr. 41min. 12·51%
48·78% 6hr. 57 min. Charging
6th Jan.—16th Feb., 1952
265 casts
100·8 tons per cast tapped
Charge to tap: 12 hr. 28 min.
Charge to charge: 14 hr. 15 min.
Refining 1hr. 48min. 12·22%
Fettling 1hr. 53min. 12·79%
Melting 3hr. 37min. 24·54%
50·45% 7hr. 26 min. Charging
24th Aug.—18th Oct., 1952
400 casts
107·7 tons per cast tapped
Charge to tap: 12hr. 51 min.
Charge to charge: 14 hr. 44 min.

Fig. D—'Pie' diagrams for production time analysis

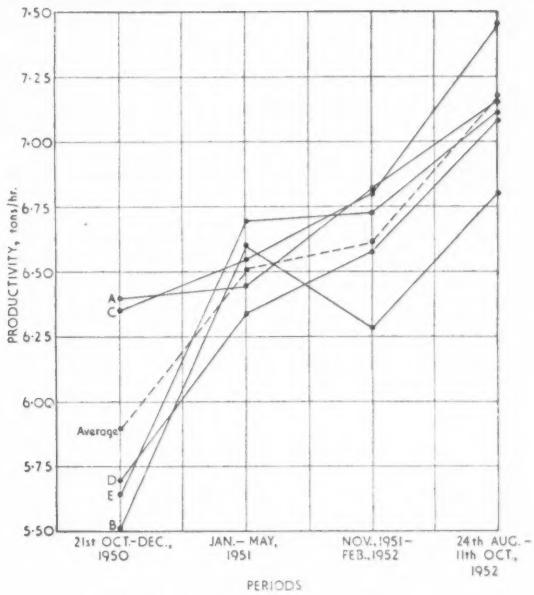


Fig. E—Productivity progress at Round Oak Steelworks Oct., 1950–Oct., 1952

Dr. **T. P. Colclough** (British Iron & Steel Federation): It will be obvious to everybody that the larger the steelmaking furnace, the higher will be the productivity figure. In analysing the figures given by Dr. Marshall, one of the most striking features is that in going from the 75-ton furnace to a 200-ton furnace the length of time per heat is almost exactly the same. If furnace operators are to attain these high productivity figures, then they must be provided with the facilities for charging the furnaces, no matter what size they may be, in a certain specified time. I want to commend to this meeting the need to have all the mechanical ancillaries tuned up to match the size of the furnace.

Again, in comparing British and American furnaces, the enormous difference that is brought about by the difference in fuel cannot be over-emphasized. The first slide that Dr. Marshall showed, indicating the possible flame temperature, the volume of waste gases and the volume of air required for combustion, teaches us a good deal. If producer gas is used instead of oil, there is at least 20% more heat passing through the chimney for the same temperature of waste gases. Secondly, with an oil flame, the possible flame temperature is 2000° C. as compared with a producer gas flame of 1600° C.; the difference in the radiating value of these two flames is enormous. If the furnace structure is at the steelmaking temperature of about 1600° C. and the producer-gas flame can generate only 1600° C., there is almost no interchange of heat. On the other hand, with an oil flame at 2000° C., there is a radiant value from that flame to the bath throughout the whole of the steelmaking operation, and this must give enhanced operation. This point is worthy of special emphasis.

Dr. Marshall has underlined the importance of the metallurgical load, and the question of the thickness of the slag layer cannot be over-emphasized. I wish that Dr. Marshall had given us a diagram showing the effect not of the slag volume but of the thickness of the slag on the surface of the metal, because that is the really important factor. During this coming year we are hoping to have an investigation on the effect of this slag thickness, and the steelmakers of this country have been asked what would be the effect on their productivity if they could have the pig iron that they would like to have. We have also asked what analysis of iron they would like, what increase of production could be achieved, and what decrease in cost of steelmaking there might be. If they could give us that information, we should have a standard by which we could judge the amount of work or expense that would be economic in producing this quality of pig iron. That, I imagine, would be a really useful step forward, and we hope that it will be taken.

Regarding furnace availability, I do not think that it is quite realistic to compare a figure of 80–81% for British furnaces with that of 90–92% for American furnaces, because there are in Britain still more and smaller furnaces than we are able to utilize fully. I think that it is fairly common in this country to operate four furnaces out of five, and that this is the main reason for the 80% availability. It ought to be known and to be on record that, in the British plants where we have the raw materials needed to operate all the furnaces that are available in the shop, we can maintain a 90% or slightly higher operation for these furnaces. The attainment of this high figure dates back to 1930. I know that it was the pride of the Lancashire Steel Corporation at Irlam that over a period of three years, pre-war, they had an availability of their O.H. furnaces of 93%. Other companies can produce similar data, and we are not backward in that way at all.

I am glad that Dr. Leckie made the point about the cost of fuel oil having a restricting effect on its use and therefore on our productivity figures. When one company in Britain adopted oil-firing, their productivity was increased by 25%, but this method was discontinued because of the high cost.

Two-pass checkers were in use in this country twenty years ago at the Irlam plant of the Lancashire Steel Corporation. As in America, this type was installed because it was not possible to get the desired depth of regenerator chamber, as the works had been erected on an old river bed. I believe that the two-pass system has been discarded, but no information is available as to the reason.

With regard to checker cleaning, which is referred to in the Report of the Productivity Team,* facilities for cleaning the checkers by pneumatic action were developed and applied to the Ebbw Vale O.H. furnaces in 1938, and these furnaces also have attained 90% availability.

Figure 4 of the paper indicates the difference in productivity with different bath areas. In the Discussion it has been pointed out that 80-ton or 100-ton furnaces are invariably charged with an additional 20–30 tons, and higher productivity is achieved; this apparently contradicts the conclusion of Fig. 4. There is, however, no real contradiction, because the curves in Fig. 4 refer to a furnace of a particular size. When a 100-ton furnace, having so many square feet per ton, is charged to 120 tons, it is no longer a 100-ton furnace, and the slope of the line showing the effect of hearth area is not the slope of the line where size is compared with production per hour. More tons per hour are achieved, even if the furnace is over-charged.

Emphasis has been laid on the decrease of fuel consumption with the larger furnace. It is obvious that with the very large furnaces there is not likely to be the same number of therms per hour lost by radiation and similar factors per ton of metal charged, but I think that there is another fundamental point. In the very large furnace as compared with the small one—say, 200 tons as against 80 tons—a certain number of gallons of oil per hour are being burnt during charging and melting, and the radiant flame generated has a much larger area of bath to absorb the radiation. I think that it is in this radiation factor that the secret will be found to lie. I hope that the research work that has been carried out on this subject at Ijmuiden, when applied to our British furnaces, will enable us to make progress in our own research work this year.

Mr. **M. P. Newby** (B.I.S.R.A.): Dr. Marshall has mentioned oil burners and oil atomization, and also model work on furnaces. I was glad that he did not mention convergent–divergent nozzles on burners. Several times recently we have heard people mention these as though they were a sort of panacea and it were only necessary to put one on the end of a burner for everything to improve tremendously. We have recently done some work on this problem at B.I.S.R.A., and our conclusions are not quite on those lines.

We have come to the conclusion that there is a considerable field for improvement in the design of burners, and that, theoretically, it should be possible to reduce steam quantities substantially if we could design a really efficient burner. We are making every effort to achieve this. Not only do we want more efficient burners, but if we can use better-quality steam on our burners we can also reduce the quantity of steam, because, as Dr. Leckie has said, we can see no reason for putting large quantities of steam into furnaces. We are glad to see that there is a tendency now to use higher-pressure and higher-temperature steam on burners.

* " Iron and Steel," Productivity Team Report: 1952, London, Anglo-American Council on Productivity.

Several model experiments have recently been made on the design of furnaces, and these have been quite fruitful, but they have been made only after the furnace has been built. We have recently carried out some experiments on a new design of furnace in which the model results show clearly the zones in the furnace where refractory wear would be severe, and the predictions were confirmed when those furnaces went into production. We feel that the time has come when the new techniques that have been developed for studying the behaviour of furnaces from simple models should be applied at an earlier stage in furnace design. We are confident that that would yield very valuable results.

Dr. **D. F. Marshall** replied: In considering the relative merits of fuel oil and producer gas as O.H. furnace fuels, Dr. Leckie appears to be assessing three factors at the same time; namely, the properties of the fuels, their relative costs, and the particular aptitude of a plant to use one or other of these fuels. The object of this section of the paper was to deal with the fundamental properties of these fuels in so far as they might influence furnace design, operation, and productivity. Fundamental differences exist wherever the fuels are applied. The question of relative costs is a separate consideration and varies from plant to plant according to fuel-using technique, plant and furnace design, and many other factors that do not affect the validity of the comparisons set forth in the paper.

The apparent need for high steam/oil ratio is theoretically undesirable, and in most cases it arises from the unsuitable nature of the steam supply of the works. The use of separate superheaters to control and condition the supply to the O.H. furnaces appears to be one solution to this problem. I know of one plant where changing over from air atomization to steam atomization actually gave marked increases in the hourly production rates. This changeover did permit the atomizing medium to be used at higher pressures, and the instance emphasizes the importance of having energy available at the tip of the burner as against the importance of the nature of the atomizing agent. Experience at the Park Gate furnaces does suggest that with central uptakes lower steam/oil ratios can be used.

Dr. Leckie is correct in assuming a change in pig-iron analysis in periods 4 and 5 of Fig. 7. Burden changes on the blast furnaces during these periods resulted in increases of averages of 0·20% of P and 0·10% of Si in the pig iron. Extra feeding of the mixer kept the silicon content of the hot metal delivered to the furnaces at the same level throughout, but the phosphorus increase was passed on to the O.H. shop and it is largely responsible for the increase in slag bulk shown. The regression line connecting Si and tons/hr. is given by the expression:

$$\text{Output (tons/hr.)} = 5{\cdot}56 - 0{\cdot}14 \left\{ \text{Si (lb./ton)} - 6{\cdot}26 \right\}.$$

The whole point of Fig. 3*b* was to show how furnace size was related to output per hour. The British value of 0·027 tons/hr. increase in productivity per ton of added capacity was obtained from the B.I.S.R.A. collected data. Using the graph of British hot metal furnaces (excluding filters), the figure is 0·37 tons/hr.

Dr. Leckie's comments on the difficulties in the way of increasing furnaces, which are caused by the wide diversity of orders in our own industry, brings to mind the statements in the Productivity Team's Report on this subject. In America, heavy price penalties are put on small orders—a factor that has encouraged the grouping of such orders by stockholders, which in turn has favoured the building of large producing units.

On the questions of bath depth and hearth area, and overloading of furnaces, I am in complete agreement with the remarks made in Dr. Colclough's contribution.

The application of single uptake design to O.H. furnaces is still new. Our own experience confirms that of other plants; namely, that faster driving and more uniform melts are two of the major advantages. We have, however, experienced considerable difficulties by excessive wear on both sides of the uptakes and by the formation of a very dense slag in the slag pockets. This latter feature was quite surprising, as basic bricks were used in the uptakes. Early experimental work on furnaces of this type has shown that both these undesirable features are closely linked with exceptionally high air preheats. These can be controlled to some extent by variations in the furnace pressure, but they are primarily a function of the furnace design. The limited evidence available from American practice does suggest that as furnace size increases the advantages of central uptake design decrease. This does not mean that there are no advantages accruing from using this design on large furnaces.

Figure 7 obviously includes furnaces of various sizes, as the object in presenting it was to express quantitatively the relation between unit size and heat input per hour. The furnace sizes range between 100 and 200 tons capacity.

I agree with Dr. Leckie's comments that we have to accept the implication of design limitation, as shown by the fact that working constant air-flow or limited air-flow changes gives faster operating rates and lower fuel consumptions than fuel/air ratio control in the majority of O.H. furnaces.

Mr. Bashforth's comments on the experience at Round Oak are particularly helpful, as they emphasize many of the points made in the report. Everyone is becoming increasingly aware of the importance of studying metallurgical load, and it is hoped that the paper and the further information in Mr. Bashforth's contribution will serve to stimulate investigation in this field. The figure quoted (two hours per furnace per week) for cleaning out the gas flues of a producer-gas-fired plant is a good example of what can be done in one particular direction to improve our producer-gas practice. Other avenues of approach, such as automatic control of producers and furnaces, have been mentioned in the paper.

The use of holes in the back wall to cool a roof is a little unorthodox, and it will be interesting to see what results are achieved. At first sight one would have expected a fairly high pressure at this point, with the possibility of flames issuing from the furnace rather than of air infiltrating.

Mr. Bashforth's experiments on gas-port size and construction give results very much in line with our own producer-gas-firing practice. The port size was progressively decreased, with benefits to production, until a stage was reached in which any growth in the chrome-magnesite constructional materials, or deposition of slag, caused a trend in the opposite direction. In effect, these changes all tended towards the higher gas velocity achieved at Round Oak by increasing uptake pressures.

I agree with the suggestion that with the larger furnaces, and particularly when driven fuels are used, more liberties can be taken in shortening heating-up schedules.

Dr. Colclough rightly stressed the importance of providing adequate charging facilities. On the majority of plants, investigations into charging equipment and charging procedure pay good dividends by increasing outputs.

The remarks on fuel properties and the properties of waste gases and flames from these fuels amplify the fundamental differences outlined in the report. Although I agree with Dr. Colclough's statement that the higher

radiating value of an oil flame enhances the entire steelmaking operation, it is probable that too little attention is being given to the transfer of heat by conduction and convection, particularly in the charging period. The present work on flame reduction might increase in value by examining this question.

Regarding the slag-layer thickness, the slag bulks reported can be taken as being proportional to slag thickness, as the furnace banks are usually very steep at the slag line, especially—as invariably occurs—when some cutting into the bank takes place. It is thought that, for the Park Gate plant at least, we have gone a long way towards answering Dr. Colclough's question on the analysis of iron required and how changes in analysis would affect costs. It is hoped that any changes he has in mind are towards improving pig-iron quality and not in the reverse direction.

As Dr. Colclough suggests, the carrying of one—or even two—spare furnaces in a shop can only be considered an expensive luxury, and it is difficult to justify by national steel demand.

The true value of two-pass checkers is still an open question. They were mentioned in the report as being one method of improving checker capacity on sites where excavation presents great difficulties. It is, however, refreshing to hear that two-pass checkers and pneumatic checker-cleaning facilities are used in this country, and also that high furnace availabilities are being achieved.

The point made regarding the advantages that large furnaces have in the form of extra bath capacity available to absorb radiation during charging and melting is equally valid when considering conducted or convected heat.

In reply to Mr. Newby, it seems possible that 90% of burner design and atomizing problems arise from the quality or quantity of steam available. It is pleasing to hear that the scaling-up of results from models to operating units has passed the experimental stage. Mr. Newby was undoubtedly aware that on many plants one essential feature affecting all the furnace design was the space available between existing column centres. In this particularly difficult field, model work might prove to be invaluable.

I should like to thank the contributors to the Discussion for putting forward some very useful points.

PROCEEDINGS OF THE MORNING SESSION: 9.30 A.M. to 12.30 P.M.

Discussion on the Papers—

TRIALS OF AN EXPERIMENTAL AUSTEEL-ESCHER METALLIC RECUPERATOR*

By J. B. Davis, W. Ernest, and H. Kay

EXPERIENCES WITH THE ESCHER METALLIC RECUPERATOR ON HIGH-TEMPERATURE FURNACES† *By H. Escher*

HEAT RECOVERY IN INDUSTRIAL FURNACES‡ *By A. Clift and C. Knight*

Mr. **W. Ernest** (The United Steel Companies, Ltd.), in introducing the first paper, said: Since the work reported in the paper, the test recuperator has been used experimentally in connection with a small melting furnace in which temperatures at recuperator entry of up to 1500° C. were measured. The furnace was oil-fired and the recuperator preheated the secondary air only. The maximum preheat obtained was in excess of 700° C., with a waste-gas inlet temperature of 1480° C. In these later tests we introduced a thermocouple into the inner shell at the end of the recuperator nearest to the entry of the hot gases. Under these conditions, maximum metal temperatures in excess of 900° C. were observed at this point, but since the data were very scanty no further conclusions could be drawn from them.

Mr. **H. Kay** (Stein and Atkinson, Ltd.): The tests outlined in our paper were carried out during the summer of 1949. Later in the same year the first four production Escher recuperators were brought into service, and these have all been in operation ever since. Three are attached to small glass-melting furnaces working up to 1450° C., and the fourth is on a rotating-hearth furnace operating at 1150° C. The glass-tank recuperators are shown in Fig. *A*. The tanks are oil-fired and the waste gases leave alongside and at almost the same level as the burner, thereafter ascending through the recuperator, which is of the parallel-flow type.

The first of these recuperators was fitted to a borosilicate glass tank, and was lined with fused alumina $\frac{3}{4}$–1 in. thick in the form of panel-brick rings tongued and grooved together. The lining was provided to protect the metal of the inner shell against the fluxing action of any borax carried over with the waste gases, but, in fact, the lining was completely fluxed away in about six months, and the recuperator has been in use on subsequent campaigns without any lining. The effect of the lining on the heat transfer was to lower the preheated air temperature by as much as 2000° C. compared with that in the unlined recuperators.

The air temperatures obtained on the three furnaces

* *J. Iron Steel Inst.*, 1951, vol. 167, pp. 66–70.
† *Ibid.*, 1951, vol. 169, pp. 39–46.
‡ *Ibid.*, 1952, vol. 172, pp. 327–339.

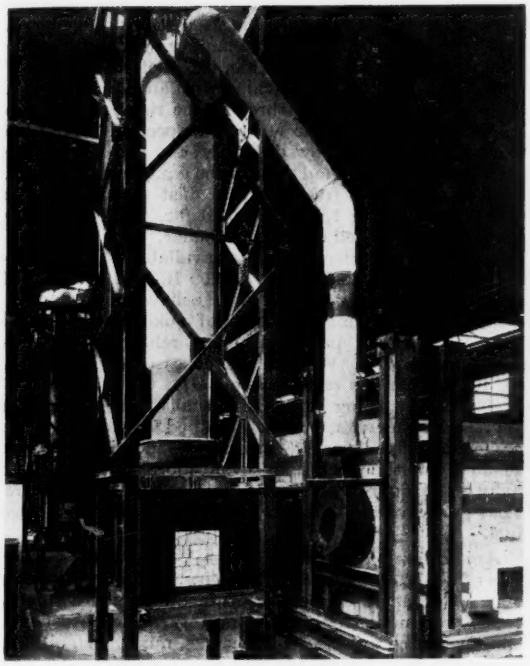


Fig. A—Glass-tank recuperators

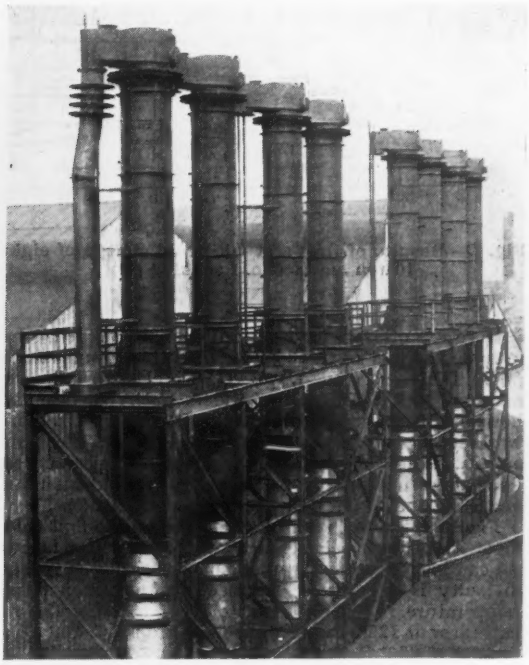


Fig. C—Counterflow gas recuperators

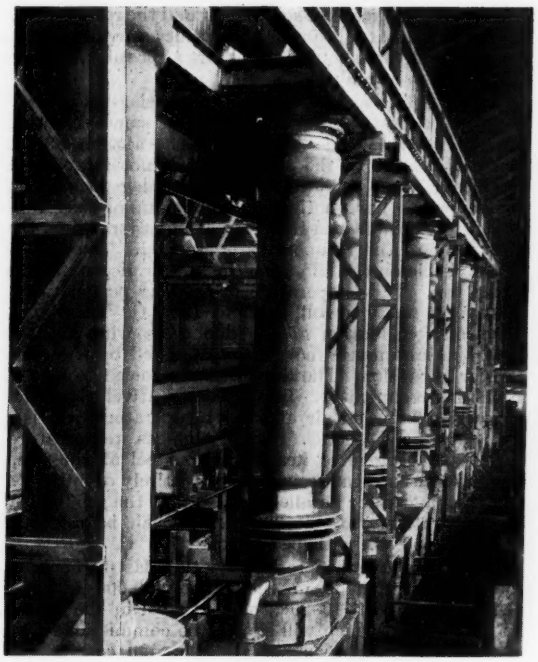


Fig. B—Austeel-Escher recuperators fitted to forge furnace

vary from 390° to 580° C., depending on the working temperature of the furnace, which varies with different types of glass.

Most of the repairs carried out on these three recuperators were due to inexperience in manufacture of this type of structure, and would not now be necessary. Some erosion, mainly in the form of pitting, occurred in one case only, but this was made good by building up the surface by arc welding ; this recuperator has been in service for almost two years since the repair, and has now been operating for about three years.

The erosion was thought at the time to be caused by ash in the fuel oil. This ash contains about 25% of vanadium pentoxide, which is known to have a fluxing action on nickel and chromium. Subsequently, however, it was decided that the real source of the trouble was sulphur, 2% of which is present in the fuel oil, and which is also present in the batch for the amber glass that was being produced. Moreover, this furnace has a sealed working-end, *i.e.*, there are no openings, so that the nature of the flame cannot be observed and deficiency of air is very possible. No such attack was shown by other tanks with open working-ends and no sulphur in the batch, but using the same vanadium-bearing oil.

Other minor repairs carried out on one recuperator have been mainly on some of the welded joints, and particularly at the lower end, which is exposed to the gases at the maximum temperature. Normally, these welds are protected by bricked rings, but after considerable uninterrupted use the bricks burn and flux away, thus exposing the bare metal. Even so, the cracks were only small and were easily repaired, and they could be avoided by better maintenance of these bricked rings.

In April, 1952, a battery of three forge furnaces, each fitted with two Austeel-Escher recuperators, was brought into service (*see* Fig. *B*). Complete tests have not yet been carried out on these recuperators, but an air temperature of 400° C. has been measured.

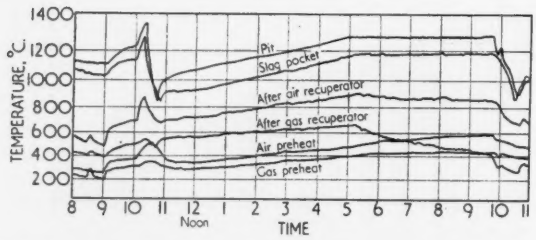


Fig. D—Results of first test with cold charge of eight 10-ton ingots (No. 1 soaking pit)

More recently we have carried out initial starting-up tests on the first of three batteries, each of four soaking pits. The pits are one-way fired with blast-furnace gas, and are 25ft. long by 8ft. wide. Each pit has two horizontal air recuperators (each 22ft. long by 2ft. dia.), working in parallel and on parallel flow. These recuperators are followed on each pit by a single counter-flow gas recuperator (65ft. long by 3 ft. dia.) mounted vertically and forming the furnace stack (Fig. *C*).

Figure *D* shows the results obtained on the first cold-ingot trial, the pit being charged with eight 10-ton ingots. As can be seen from the preliminary heating curve, no difficulty is experienced in reaching the required pit temperature. With the waste gases entering the recuperator at 1260° C., an air preheat of 625° C. and a gas preheat of 430° C. were obtained.

Our present accumulating experience, in both design and operation of these recuperators, indicates that it should be possible to design a recuperator to give an air temperature of 800° C. with trouble-free life for many years.

Mr. H. Escher (Consulting Engineer), introducing his paper, said: I am very happy to have the opportunity of personally presenting this paper and should like to enlarge on a few points and give some additional information.

Use of Preheated Blast-Furnace Gas—The recuperator which we are discussing today was developed in the early stages of the war, when increased fuel demands for forging and steel-melting operations required a better utilization of the available works fuels. Its development is thus closely connected with the preheating of blast-furnace gas or mixed gases. A wide experience has been gained in this field and 37 blast-furnace-gas recuperators, with a total capacity of 7×10^6 cu. ft./hr., have been installed or will be commissioned shortly.

It is often said that it is not advisable to preheat blast-furnace gas above 350° C. In some cases, it has been reported that the reduction of preheat from 450° to 350° C. has overcome troubles due to blockage of the recuperator by carbon deposits attributed to gas dissociation. It is probable that the shape of the heating surface, the flow conditions, the material of the heating surface, and the primary deposition of entrained dust have a bearing on this problem.

This particular recuperator has a very smooth vertical surface of fairly large curvature, the surface at all points being swept at high velocity by the gases. It does not seem possible for dry dust, either entrained with the gas or formed by dissociation, to adhere to it. This is supported by extensive experience in preheating gases to temperatures in excess of 500° C. at Port Kembla. I believe strongly that it is possible to preheat blast-furnace gas to, say, 650° C., the limit being set by the metals available for the construction of the recuperator.

Furthermore, no trouble has been experienced in preheating comparatively dirty and wet blast-furnace gas in these recuperators. The necessary pre-drying is simply effected in the inlet chamber surrounding the recuperator. In one installation, the inlet chamber is of considerable size and is provided with an internal baffle. The dried dust is blown through the recuperator, into the furnace, and up the stack. Inspection after nine months of service showed hardly any deposit in the pre-drying chamber, and none in the annular gas passage. As a result of this freedom from dust trouble, a large unit for preheating 1,250,000 cu. ft./hr. of blast-furnace gas is being installed on a steam boiler.

Extensive experience is also available on the preheating of mixed gases of up to 200 B.Th.U./cu. ft. and at temperatures up to 480° C. I believe there is great scope for preheating mixtures of coke-oven gas and blast-furnace gas, particularly for reheating furnaces and soaking pits. With mixed gases of 230 B.Th.U./cu. ft., the air/gas ratio is about 1/1, the specific heat of the fuel gas being higher than that of the air, so that appreciable benefits can be obtained by using highly preheated mixed gases. It may be possible to save 20–30% of the fuel and—even more important—to reduce the quantity of coke-oven gas in the mixture. That gas, diverted to other uses, may replace imported fuel.

Application of the Recuperator—A total of 45 soaking pits of 40–120 tons holding capacity, equipped with this type of recuperator, have been installed or are shortly to be commissioned in Britain, U.S.A., and Australia. The fuels used are blast-furnace gas, mixed gas, oil, and natural gas. A typical unit for a medium-size pit, installed horizontally, is shown in Fig. 3 of the paper. The recuperator is mounted on two longitudinal beams by means of rollers which permit free movement for expansion. The recuperator is bolted at one end to the slag pocket of the pit. The slag pocket is small and is totally steel-encased, so that there is a minimum loss of temperature between the soaking pit and the recuperator. This is a point to bear in mind; flues carrying high-temperature gases should be as short as possible, to keep heat losses to a minimum.

The air enters at the bottom, at the slag-pocket end of the recuperator, and flows in the same direction (parallel flow) as the flue gases. The section of the recuperator next to the slag pocket is not lagged. It provides a 'heat barrier' between the slag pocket and the recuperator, preventing the building up of dangerous temperature conditions by external radiation, when the air supply to the recuperator is stopped. The hot-air box is visible on the left, with the hot-air discharge pipe at the top. The temperature in the slag pocket, when the steel is ready to roll, is about 1240° C. There is no provision for dilution of the flue gases with air, but simply an automatic fuel cut-off operated by the recuperator expansion. The flue gases are cooled to 850° C. in the air recuperator. In the comparatively long flue connection between air and gas recuperator there is a drop of about 100° C. in the flue-gas temperature. Owing to shortage of heat-resisting steel at the time, the blast-furnace-gas recuperator is entirely of mild steel and is arranged for parallel flow, so that the gas preheat is comparatively low at 320° C. The air is preheated to about 650° C., with peaks up to 700° C.

With the above moderate preheat of blast-furnace gas, fuel consumption is in the range 750,000–1,000,000 B.Th.U./ton, with 10–20% of cold steel in the charge. In new plants, which will shortly be commissioned, the gas preheat will be higher and the fuel consumption lower.

The application of these recuperators to large continuous reheating furnaces goes back nine years, when

an existing coke-oven-gas-fired billet-heating furnace was converted to blast-furnace-gas firing. Another furnace of very similar construction was started up in 1949. Details of construction, performance, and maintenance of these furnaces are given in the paper. On the second furnace an output of 42 tons/hr. on straight blast-furnace-gas firing (92 B.Th.U./cu. ft.) can be obtained, and by the addition of some coke-oven gas the output can be raised to 55 tons/hr. There are advantages in using a variable mixture rather than a fixed mixture. The high calorific mixture may be required when the furnace operates at maximum output, but there are many periods when the furnace works at moderate outputs or is just holding the steel, and it could then be fired on straight blast-furnace gas, thus saving coke-oven gas for the melting shop or other more valuable uses. This variable-mixture firing is at times helpful in balancing the fuel position of the works.

There is no doubt about the advantages of blast-furnace gas for heating steel. Figure 10 of the paper shows the billet temperature *versus* furnace location for blast-furnace gas and coke-oven gas. With blast-furnace gas the billets are better soaked, and therefore better rolling follows; this, combined with the smaller scale losses, also improves the life of the rolls in the mill. There is scope for blast-furnace-gas-fired continuous furnaces of large capacity. The design shown in Fig. 1 of the paper is for a single-zone, blast-furnace-gas-fired furnace, with an output of 70 tons/hr. This design is based on the ability to preheat blast-furnace gas in these recuperators above 600° C. The flue-gas outlet end of the furnace is designed to give an almost unrestricted passage for the very large volume of high-temperature gases into the recuperators.

Two large slab-heating furnaces, each of 100-tons/hr. capacity and fired with coke-oven gas, are being built in Australia.

Users often say that, with rich fuels, it is difficult to use very high preheats of the combustion air. No doubt troubles would be encountered with standard designs and arrangement of burners. However, a large number of small jets at high velocity would give rapid recirculation of gases within the combustion chamber, and it should be possible to use preheats of 650–700° C., even with fuel oil or coke-oven gas. Further experimentation in this field is required.

In regard to the application of this recuperator to steel-melting furnaces, the satisfactory experience gained on several glass-melting furnaces indicates that such a development is possible.

Mr. **C. Knight** (Stewarts and Lloyds, Ltd.) presented the third paper.

Mr. **R. Maxwell** (Consett Iron Co., Ltd.): The present necessity for economy emphasizes the value and importance of waste-heat to industry, and it is unfortunate that the practical attainment of waste-heat recovery is not a simple matter. Broadly speaking, there are three methods of reaching the desired objective: (1) The recovery of waste heat in the form of steam only; (2) the return of waste heat to the furnace; or (3) a combination of (1) and (2), the choice depending on the total heat content of the waste gases from the primary process.

The return of waste heat to the furnace may be achieved by either recuperation or regeneration, one factor governing the choice being the suitability of the high-temperature constructional materials available. In addition to delivering extra B.Th.U's, accelerating the rate of combustion, and increasing the flame temperature, method (2) has the further and very important advantage that lower-grade fuel gases can be used for the primary heating process. This feature is being utilized in a new soaking-pit installation at Consett, in which it is expected that all ingot heating will be carried out with blast-furnace gas alone, leaving coke-oven gas for open-hearth furnaces and other purposes.

There are twelve pits, each fitted with Escher recuperators for both air and gas, and preliminary results of heat recovery are very promising. On each pit the gas recuperator will preheat blast-furnace gas in counterflow, while the two air recuperators preheat the combustion air in parallel flow. I suppose that, in a metallic recuperator, counterflow working gives a higher heat to the fluid and parallel flow a lower heat to the metal, but perhaps Mr. Escher can give the factors governing the choice between counterflow and parallel-flow working ? In a furnace fitted with two or more air recuperators how is equal waste-gas loading of them achieved and maintained ? Equal subdivision of the waste gas to the air recuperators must be important and any dividing device would have to withstand high temperatures.

Mr. Escher stated in his paper that there are good prospects of applying his recuperator to open-hearth furnaces. Has any progress been made in this matter ? The degree of heat recovery in recuperators or regenerators is largely a compromise between pressure drop and heat transfer. The Escher recuperator, with its straight-through passages, appears to offer some advantages in regard to pressure drop, particularly with clean gas, but is it at the expense of some heat-transfer efficiency ?

The results of the trials of the experimental recuperator might have included the temperature of the final waste gas leaving the recuperator, and also some comment on the degree of completeness of the heat recovery. One of the reasons for carrying out the trials described in the paper by Davis, Ernest, and Kay was that the recuperator appeared to offer some advantages over many existing types. Perhaps the authors will tell us if their tests have confirmed this and will also say something about these advantages ?

The paper by Clift and Knight is a very interesting account of the various forms of heat-recovery plant, and shows the remarkable response it has made to the more exacting rolling-mill demands brought about by improved mill equipment. The question of recuperation *versus* regeneration is controversial. Can the authors give the latest conclusions on this old problem ? With the improvements in modern technique and recuperator design, is it possible that regenerators will eventually be confined to really high temperature processes such as the open-hearth furnace ?

The recovery of waste heat by means of the gas turbine has very interesting possibilities. If the heat exchange is made from the flue gases to the air, then the turbine works as a hot-air engine, and generation of power by this means seems to be very promising. I believe that the Gas Board are now building a unit on these lines. What are the possibilities of using the gas turbine in the recovery of waste heat in the iron and steel industry ?

Mr. **Escher**: Parallel flow is used on installations in which the flue-gas temperature entering the recuperator is in excess of 1100° C. and the desired air preheat is high. In the particular case of a blast-furnace-gas-fired soaking pit, the flue gases enter the recuperator at 1290° C., and the metal temperature of the recuperator at the flue-gas inlet is about 650° C. At the outlet end the flue-gas temperature has dropped to 900° C., the air temperature is 810° C., and the metal temperature is about 860° C.

Thus, under these conditions of parallel flow, a metal temperature of 900° C. cannot be exceeded, whereas with counterflow, metal temperatures approaching the flue-gas inlet temperature, *i.e.*, above 1200° C., could be

obtained. With parallel flow the metal temperature is fairly uniform from one end to the other, *i.e.*, from 650° to 860° C., and good use is made of the heat-resisting steel. With blast-furnace-gas-fired pits, the parallel-flow air recuperator is then followed by a counterflow gas recuperator, so that the flue gases can be cooled finally to fairly low temperatures.

The splitting of the flue gases between two recuperators in parallel is an arrangement which is being used on large soaking pits. Tests carried out on several installations have indicated that the distribution, both of the flue gases and of the air, is very even between the two units. The units are manufactured to close engineering tolerances, and such even distribution is to be expected. If it was necessary to adjust the distribution of the flue gases, the damper would be placed on the outlet side of each recuperator, where the flue-gas temperature is in the region of 850° C.

In installations where four recuperators are in parallel, such as continuous-heating furnaces, the recuperator expansion is used to distribute the flow of gas through each recuperator.

Mr. Maxwell asks about the application of this recuperator to open-hearth furnaces. A small 4½-ton unit was built at Port Kembla, mainly to test the recuperator. The flue gases passed through a water-cooled nozzle, located in the roof, directly into the recuperator at 1600° C. There was no difficulty in dealing with that temperature. The high velocities in the furnace caused severe erosion of the brickwork, and after two weeks the side walls, which were of silica, were just chewed out. I believe that, with the experience of glass-melting furnaces, there appears to be a good chance of applying this recuperator to the open hearth. Results on a small experimental unit indicate that highly preheated air used with coke-oven gas in a well-mixing burner gives very fast melting. The problem of obtaining a uniform temperature of the bath could be overcome by proper arrangement of the burners.

Mr. Ernest: In answer to Mr. Maxwell's first point, the recuperator was not designed to extract the maximum amount of heat from the waste gases, but purely as an experimental unit that would enable a wide range of conditions to be observed. Owing to space limitations it had a heat-transfer area of only 120 sq. ft., and air pressure was limited to 18 in. W.G.

The waste-gas temperatures after the recuperator were observed but not included in the paper. As an example, in Test No. 20, where the waste-gas inlet temperature was 1408° C., the waste-gas outlet temperature was 830° C., the air preheat being 600° C. In counterflow the temperatures were 900°, 550°, and 430° C., respectively.

The advantages to be anticipated from metallic recuperators of the Escher design might be summarized as follows :

(i) Ability to withstand high gas temperatures without air dilution
(ii) Low pressure-loss on the waste-gas side and freedom from air leakage
(iii) High unit-area heat transfer due to utilization of gas radiation, which should save heat-resisting material, space requirement, and cost
(iv) Use of recuperators as chimneys.

It will be clear that these advantages mainly accrue on furnaces with high waste-gas temperatures. It can be said that the trials confirmed the technical aspects and theoretical calculations.

Mr. Knight: Mr. Maxwell has raised the important question of regenerators *versus* recuperators. It is hardly to be expected that this matter can be decided here and now. Regenerators have a simple construction, are robust, and are easy to handle, but they are bulky and need a relatively complicated venting arrangement. Recuperators are compact. With the relatively high temperature gases used in them nowadays, the control is less simple than formerly ; even so, it is possible to make a good job of them. We think that regenerators are most likely to be confined to particularly high temperature work such as in open-hearth furnaces, and that for normal reheating furnaces they are likely to be replaced. This view is not necessarily held universally, and regenerators are still favoured in some places for various ingot reheating furnaces, even of the car type.

The question regarding gas turbines is really one for the mechanical engineer. Presumably the application in mind is that in which the waste gases are used to increase the turbine driving power of compressed air by using a heat exchanger. For good efficiency, the temperature of the waste gases should not be below about 800–850° C. In our plant we usually endeavour to take as much waste heat as possible out of the gases in the furnace itself before passing them on to a secondary waste-heat recovery unit, and for this reason our gases are generally below that temperature. Nevertheless, we are keenly interested in the possibility of using a turbine as part of a waste-heat recovery unit, although it is not yet possible to give any information on this matter. We are at present examining its possibilities.

Mr. Escher: In regard to the use of gas turbines on the Continent, a plant in Luxembourg using blast-furnace gas drives a 5400-kW. alternator and provides also blast air for the Bessemer shop or the blast-furnaces. This plant has been in service for more than 8000 hr. without the slightest mechanical trouble. The combustion gases enter the turbine at 580° C. As would be expected with blast-furnace gas, the auxiliary equipment, such as heat exchangers attached to the gas turbine, is very bulky. I believe the application of gas turbines to the steel industry for using waste heat from the waste gases of furnaces would be confined to heating compressed air in a heat exchanger by the waste gases and then passing the air through an air turbine, the exhaust being used as combustion air after further reheating. The most likely field of application may be the open-hearth plant, where waste-heat boilers could be replaced by air turbines.

Mr. C. H. Williams (Stein and Atkinson, Ltd.): Figure *E* shows the foundations for four pits which will have Austeel-Escher recuperators. The simple concrete raft is only 4 ft. 6 in. below mill floor level at the front and 5 ft. 6 in. at the back, and there is not a single flue below this level. The relative depth can be observed by comparison with the ingot chariot rails in the foreground. The length of the foundation is 65 ft. and the depth, *i.e.*, from front to back, is 95 ft., on which four pits will be built holding 400–600 tons of ingots and having a weekly heating capacity of over 5000 tons. Figure *F* shows the first eight pits at Consett, which are nearing completion and on which preliminary tests have been made; their similarity to the Lysaght pits will be noted.

In their paper, Clift and Knight seem to condemn refractory recuperators. Although I am an advocate of metallic recuperators, I also favour refractory recuperators, with which many fine installations have been made in Britain, *e.g.*, on soaking pits and slab furnaces for continuous hot strip mills. There is a case for both types and the choice depends on many considerations, including siting.

Have the authors any experience of needle-type recuperators having the outside needles removed so as

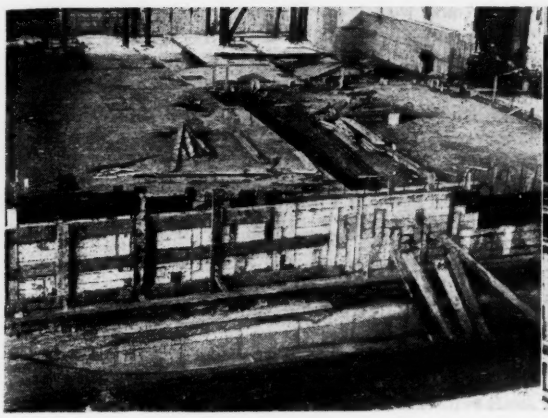


Fig. E—Foundations for four pits

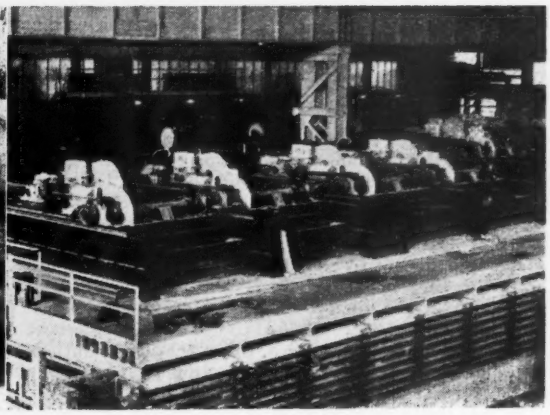


Fig. F—Top view of eight pits

to avoid trouble with deposition? If so, it would be interesting to hear the effect on preheat.

I do not think that the heating rate of 20–30 min. per inch of diameter is high; in a continuous furnace heating slabs 8½ in. thick, the rate is 17·7 min. per inch of thickness.

I am surprised that the authors do not make more mention of blast-furnace gas, which is usually the cheapest and often the best fuel. Certainly, where both air and gas are preheated—and this is necessary for any high-temperature process—there is little heat left in the waste gases for use in raising steam.

The authors' Table V is based on the use of oil fuel and hot charging. Gas, when available, is usually preferable to oil for such a duty. The horse-power for induced-draught fans seems to be extremely high. In Alternative 3 of Table V, the authors dispense with air or gas heating and rely entirely for economy on the waste-heat boiler. For all high-temperature and highly rated furnaces it is an advantage to use preheated air, even with oil fuel, and in the case of lean gases to preheat the gases as well. It is our experience, both in Britain and abroad, that the more reliance is placed on waste-heat boilers the worse is the furnace practice; this always seems to deteriorate rapidly, to provide more waste heat at the boiler.

There is no one way to economy and each case has to be judged on its own merits, but I am very attracted by the simplicity of the Escher recuperator, which requires no large flues, chimneys, or heavy-duty fans. In a number of cases this recuperator has been built either in the form of an inverted U or purely horizontal, thus forming an easy connection to a waste-heat boiler if desired.

Mr. Knight: The first point raised by Mr. Williams is the use of carborundum tiles in the tower recuperator. This unit was developed, as we have said, to try to reproduce the unit developed in America. It was intended to have a number of these units in line in the spaces between the rolls of a conveyor track. The carborundum tiles stood up very well, even under the worst conditions. We ran the furnace continuously for well over a month and then shut it down, thinking that it was due for destruction. At one of our plants recently, however, an urgent need was felt for a furnace of this type, and although this unit had been in store for about two years, it was taken just as it was, erected in that plant, and put into service. The unit has since worked well, so that we can say that carborundum tiles have proved quite satisfactory here.

In regard to the needle-type elements, we have never deliberately broken off the outside needles, but sometimes they have been broken off accidentally, and we have noticed that if many needles are broken off the recuperator efficiency decreases. When that happens we replace the elements.

As to heating rates, we quoted in the paper a heating rate for ingots of 20–30 min. per inch of diameter. These ingots are 21½ in. in dia. and the heating rate is an average covering about six months' operation. For short periods this has been improved upon; for example, for periods of about 3 hr., heating rates of 16 min. per inch of diameter have been reached without evidence of badly heated steel; these ingots were 16½ in. in dia.

In regard to blast-furnace gas usage, where uprising fuels are concerned we do our best to integrate, but, even so, our fuel demands are considerably in excess of uprising fuels, and we are forced to import from outside sources. We use blast-furnace gas whenever possible and conserve our coke-oven gas supplies for those units that require richer fuel. We make use of uprising tar, but have to depend upon outside sources for other fuels (oil in our case), which is the reason why use of oil is made on many of our furnaces. In the slab-heating furnace referred to in Table V, tar fuel and not oil fuel is used. We have also laid on to the furnace mixed gas, and use one or the other (and occasionally both at once), depending on our fuel position at the time.

The last point is the question of induced-draught fans. Table V in the paper was prepared from estimates made before the furnace was built. This was because various approaches had to be made to see whether we should put in recuperators or boilers or both. In this case, which I think is an exception, the site was such that we could not put in the size of recuperator that we should normally use for the size of furnace, and that meant installing one of very restricted capacity. This would have two influences: firstly, the air preheat would be nothing like what is possible with a good recuperator, and secondly, the very small passages would offer such a restriction to gas flow that there would be a very high pressure-drop and a much heavier duty fan would be needed. This is shown in Alternative 1, where an induced-draught fan as high as 150 h.p. would be required. In Alternative 2*a*, we took the same recuperator, again on paper, and in an attempt to recover further waste heat

we added to it a waste-heat boiler. This imposed still more pressure-drop in the waste-heat system, and we estimated that to obtain satisfactory draught conditions we should have to use a fan of 170 h.p. I agree that this seems incredibly high. In an attempt to overcome this problem, we reversed the positions of the boiler and recuperator, but in this case, as you will have seen from the figures, the position was even worse, and we would then have had to employ a fan of 210 h.p. That was completely out of the question, so we decided to adopt what we thought was the sensible view and to forget about air recuperation, knowing that the fuels we used would be sufficient to give us a good flame temperature in the furnace using cold air. The waste-heat losses from a furnace of this type would, of course, have been considerable, and so we decided to use ample waste-heat boilers away from the furnace, where the site conditions were not so restricted, and by this means try to obtain a good overall efficiency.

In actual fact these furnaces had to be put into operation without the waste-heat boilers, as we were waiting for the completion of that part of the installation. Using cold air, we heat satisfactorily from cold. Table V is stated to be based on hot-charging, which was the intention at the time, but since then we have used cold-charging. On cold-charging and going to 1250–1280° C., we are operating at a heat input of about 30 therms per ton of steel, which we consider to be reasonable, bearing in mind the improvement in overall efficiency that will be obtained from the waste-heat boiler.

Mr. **Neil H. Turner** (Appleby-Frodingham Steel Co.): Mr. Escher mentions the use of mild steel for a recuperator on a reheating furnace using blast-furnace gas. Does he have any trouble with carbon deposition ?

I had hoped that the paper by Clift and Knight would discuss more practical points and would give more information on the troubles which may occur with the type of recuperators that they have used. If they have had any such troubles, which, in the case of the gas recuperator, arise both from carbon deposition and from breakage of elements, what methods have they used to overcome them ?

These authors make no distinction between recuperation from continuous and from intermittently charged furnaces, although actually two different problems are involved.

On page 331, they say that the top bank of the metallic elements in the recuperator is in 35% Cr iron and the centre bank is in normal heat-resisting iron. What is the characteristic of that so-called normal heat-resisting iron ? I have the impression that it is not exactly heat-resisting.

The authors say that the difficulty of obtaining satisfactory refractory material was one of the reasons for changing from regenerator to recuperator. This may be the case with recuperators, but it certainly is not so with regenerators, where the brickwork, as such, is not the cause of many difficulties. However, the metallic recuperator, being fully enclosed, is at least nominally tight and there is no danger to health, whereas with the regenerator there is always the possibility of leakage, and the preheating of blast-furnace gas may lead to some danger.

Recirculation is mentioned as a form of heat recovery. I regard recirculation more as a means of achieving in the furnace certain temperature conditions which could also be achieved in other ways. Any incidental heat recovery in this case is a minor factor.

On the question of waste-heat boilers *versus* recuperators, we have an ingot-heating furnace which is somewhat similar to the type described by Clift and Knight, and we have recuperation of both gas and air, with a resultant thermal efficiency of a similar order to that obtained with the waste-heat boiler. Waste-heat boilers have a few disadvantages; *e.g.*, they can operate only when the furnace is in operation, and the load which they can take is limited to the load on the furnace. This means that if they were used for power generation and there was much fluctuation in power demand or supply, there would be either an appreciable waste of steam or an inability to take care of the demand. Therefore I believe that, if possible, recuperation, making use of the recuperated heat within the unit itself, is very much to be preferred to the use of waste-heat boilers.

Mr. **Escher**: The original blast-furnace-gas recuperators at Port Kembla are built entirely of mild steel, with a brick lining on the inside. The gas is heated up to 500° C. There is no evidence of carbon pick-up. The latest unit installed is also an all-mild-steel unit, as described, but without an internal brick lining. The unit is 25 ft. long and 3 ft. in dia. Examination after nine months' operation revealed no signs of corrosion. There was a fine deposit of powder only on the flue-gas side, perhaps $\frac{1}{8}$-in. thick, which appeared to be an effective protection against oxidation of the mild steel. That coating contained 23·5% of iron, 2·3% of copper, and 6·4% of sulphur in the form of phosphates. The origin of the copper is difficult to explain. It appears that mild steel can be used for the construction of blast-furnace-gas recuperators for comparatively high metal temperatures, to give a long life.

Mr. Turner referred to the safety aspect of blast-furnace gas. Most of these recuperators are placed in the open in the form of a stack and any possible gas leakage is not likely to cause a gas hazard. The handling of the blast-furnace gas has been very simple. The recuperator can be steamed out when necessary in a matter of one minute, and all the spaces are certainly well swept by the steam. At weekends the butterfly valve is closed. There is a slight leakage through this valve, allowing a small amount of gas to burn in the burner. In large furnaces, such as reheating furnaces, that are provided with two fuel headers, one for blast-furnace gas and one for coke-oven gas, steam is let into the blast-furnace-gas header when changing over to straight coke-oven gas. This prevents air from getting to it and eliminates any possibility of an explosion.

Mr. Knight: On the question of possible recuperator breakdown, we have used gas recuperators for several years for preheating blast-furnace gas or very lean mixed gas, but we have only recently done this in needle-type elements. Previously we used mild-steel tubes, but in locations where gas preheat was reasonably low (about 100–200° C.) owing to low-temperature waste gas. No troubles arose other than the normal maintenance troubles dealt with once or twice a year. When, however, we used the needle-type recuperators in the soaking pits illustrated, trouble arose owing to dissociation in the blast-furnace gas. We have taken precautions against this by deliberately limiting the preheat to a maximum of 300° C. To do this we have to dilute the waste gases, which leave the air recuperators at temperatures of about 450–500° C., down to a maximum of 400° C. Although this has not entirely overcome the trouble, it has eased the position considerably.

In regard to the application of recuperators to furnaces for continuous or intermittent operation, we mention in the paper that we did once put a recuperator to a furnace working intermittently, and it failed dismally because the gases reaching it were passing through cold flues and had no chance to build up to what would have been the ideal temperature for heat recovery. In a recent scheme

to put down another similar furnace unit, we are leaving recuperators out altogether.

I would refer the question of the composition of the iron used for the centre bank of the recuperators to Mr. Brown. To the best of my knowledge it is an iron containing about 12½% of chromium and is capable of resisting temperatures up to 800–850° C.

We regard recirculation in our galvanizing furnaces as a form of heat recovery, although this may not have been the most important feature in design. Normally, galvanizing pots are fired direct, but with the precaution of a refractory baffle between the flame and the steel or iron kettle. Under those conditions, however, the gas velocity is relatively slow. By putting down a recirculating unit it is possible to speed up the gas velocity considerably, and it improves the efficiency a great deal. The discharge gases, we find, are a little lower, if anything, than would normally be expected with direct firing.

I must agree that the use of waste-heat boilers on a furnace may not always be a good thing, because one may be faced with the need for running a furnace to raise steam. We are fortunate in having large installations, and we are able to turn the steam raised in the waste-heat boilers into the steam mains, to supplement the steam raised from the normal process boilers. Wherever possible, however, we take the precaution of laying a supplementary fuel on to the boiler—gas or oil, as the case may be—and this enables us to run the furnace more or less independently of the boiler, which is left to take what it can from the furnace. The economy of the boiler is a question which has to be considered in each individual case. As we have tried to point out, the fuel position is gradually worsening, and everything that can be done in this respect is well worth while.

Mr. **L. S. Brown** (Newton, Chambers and Co., Ltd.): The papers by Escher and by Davis, Ernest, and Kay describe a metallic recuperator that is new to Britain, whereas the paper by Clift and Knight describes a metallic recuperator that has established itself.

On page 69 of the paper by Davis, Ernest, and Kay, it is stated that 50 tests were carried out with a nominal run of 30 min. per test. I wonder whether their results are really satisfactory and reliable, since it is usual to run such tests for several hours.

Table I of their paper gives test results on the recuperator in parallel flow with temperature and load conditions corresponding more or less with the designed output. Tests *G*6 and *H*39, for counterflow, were operated, however, at much lower temperatures. It would have been interesting to compare preheat and metal temperatures at the elevated waste-gas temperatures for counterflow.

The authors' Fig. 5, page 70, is extremely interesting, and represents the efficiency of the recuperator over a wide range of loading. It appears that the maximum air preheats on each curve occur at a furnace loading of about 2200 cu. ft. of gas per hour, but the downward plunge of each curve, as this loading decreases, should be noted. Does this not mean that the recuperator is inefficient over a wide range of load, and is this not due to its being of the radiation type? Again, has a leakage of waste gases, which is given as 10%, any bearing on this? I suggest that, with the type of metallic recuperator to which Clift and Knight refer, the characteristic curves are better over the load range, owing to a combination of radiation and convection heat transfer.

Mr. Escher's design of recuperator has much to commend it where a thick layer of incandescent gas can be used. It is interesting to note that an extended heating surface in the shape of fins is used to achieve convection transfer in the cold end of the recuperator, and also that whirlers are fitted. Have these whirlers been fitted in horizontal recuperators and, if so, with what economic effects? Has increased preheat compensated for the additional friction loss of the gases and the building up of deposits on the heating surface, especially about the whirlers?

On page 332, Clift and Knight suggest that the troubles experienced with corrosive and dirty gases can be partly overcome by correct design; they then state that recuperators should be built on a unit basis. Do they mean that a faulty recuperator unit replaced by a similar spare one is correct design? Spare recuperator units are extremely useful for replacement purposes under certain arduous working conditions, but corrosion and deposit of solids on the heating surface is a function of the design not only of the recuperator but often of other parts of the plant, and these troubles can only be overcome by alteration in design. I should like the further views of the authors on this matter.

In regard to future developments, over the past 20 years designers of heat-transfer equipment seem to have crammed the maximum amount of heating potential into the smallest possible space, without much thought for availability and very often to the detriment of good design. Today, designers find that purchasers are more discriminating and it is more than ever necessary to produce the right goods for the right job. Designers still have a long way to go to produce metallic recuperators suitable for the elevated temperature and conditions encountered in Britain.

Mr. Williams raised a point on the elimination of needles from the Newton tube. The needles are eliminated on the outside of the tube under certain conditions, such as when very dirty gases are used. This obviously reduces the heating surface, and more tubes are required for a given output.

Mr. **Ernest**: Longer test runs would have been desirable, but the availability of the furnace was limited. In any case, the only variable to be altered on any day was the air flow, and since the thermal capacity of the recuperator was small, steady conditions were obtained fairly quickly. Repeat tests indicated that results could be reproduced within narrow limits.

In comparing parallel flow and counterflow, Mr. Brown presumes quite correctly that for similar waste-gas temperatures the air preheat and maximum metal temperature are higher in counterflow than in parallel flow. As stated in the paper, the purpose of adopting the parallel-flow scheme for high waste-gas temperatures is to keep maximum metal temperatures at a safe level without air dilution of the waste gases.

The shape of the characteristic curves of Fig. 5 is influenced at the low flows by the small scale of the experimental unit, since the external heat losses represent a large proportion of the thermal throughput. In production-size recuperators the curves would be flatter and, in fact, preheats would decrease with increasing flows. This feature would be less marked with convection-type recuperators, but Fig. 5 indicates a variation of only 7% for a flow range between 1200 and 3600 cu. ft./hr. of coke-oven gas. The leakage figure of 10% is estimated from the heat balance, and includes metering errors; it is not thought to influence the performance curves to any extent.

One cannot readily accept Mr. Brown's use of the term 'efficiency' in connection with heat-recovery devices, unless it is defined. The ratio of heat in air leaving exchanger to heat in waste gases entering exchanger is fallacious when comparing dissimilar conditions. The thermal ratio of a heat exchanger can be

brought as close to unity as desirable by increasing the heat-transmitting surface area, and must always be related to economic considerations.

Mr. Kay: Answering Mr. Brown's point about the efficiency of the recuperator over the gas flow range, I would say that the experimental recuperator was designed to compare calculated results with those obtained in practice. However, with the soaking-pit installation on which we made preliminary tests at a blast-furnace gas flow of over 200,000 cu. ft./hr. and a pit temperature rising from 1180° to 1280° C., an air temperature rising from 500° to 620° C. was obtained, with a gas preheat rising from 320° to above 400° C. As the gas consumption was reduced to 50,000 cu. ft./hr., the gas temperature dropped slightly to 360° C., the air temperature remaining about 600° C. In other words, there was not a very great difference in the gas and air temperatures at the lower rate of flow. The temperature of the waste gas leaving the top of the gas recuperator (which, of course, represents the stack) at the beginning of the heating, when the gas supply was highest, reached a maximum of 670° C. for a short time, but gradually decreased as the flow was reduced, so that finally it was only 20° C. higher than the temperature of the preheated blast-furnace gas.

In other words, the recuperators on a production job have a fairly steady characteristic throughout the flow range, and do not show the marked dip to be seen in Fig. 5, which is due mainly to the small size of the experimental unit.

Mr. Escher: I have not used whirlers in gases that are heavily dust-laden. The flow of the gases to the outer periphery might also cause additional deposition of dust on the heating surfaces. Slight deposition occurs at protruding welding seams, but there is very little on the smooth surfaces. I would not recommend whirlers for heavily dust-laden gases; there are other means of increasing the heat transfer which are less liable to be affected by dust. Fins have been used, as Mr. Brown says, in these recuperators, where the outlet temperature is fairly low. For instance, on a reheating furnace fired with coke-oven gas, the final exit temperature of the flue gases was only 280° C. However, this type of recuperator is specially intended for high-temperature furnaces and would not replace other types of recuperators which utilize mainly convection for the heat transfer.

Mr. M. W. Thring (B.I.S.R.A.): The Escher metallic recuperator very cunningly solves the problem of overheating the metal; on the other hand, the temperature of preheat is limited to about 800° C. I believe that the metallic recuperator is right for a counterflow furnace, such as a pusher furnace, but for soaking pits, where the gases must leave the furnace at 1000° C. or rather more, a limitation of preheat to 800° C. is fundamentally unsound. It is the efficiency not of the recuperator alone but of the system as a whole that is important. Mr. Escher gave some figures for therms per ton in the soaking pit, but not for the therms per ton-hour for holding in the soaking pit, which is where the maximum preheat is important, because the gases are going out at the highest temperature.

Much has been said about the time of heating per inch. If the bottleneck is the heat-transfer coefficient between the gases and the charge, then time per inch is correct, but if it is diffusion of heat through the metal itself, then we should deal with times per inch squared. Are times per inch used on theoretical grounds or as a result of experiment?

The choice of the method of preheat depends essentially on the temperature at which the gas must leave the furnace. On a pusher furnace, where the gas can come right down in temperature, a metallic recuperator is obviously correct; but for a soaking pit, where that is not so, a regenerator should be better than a recuperator.

Mr. **Escher:** It seems from what Mr. Thring has said that, for a furnace with exit gas temperatures above 1000° C., the refractory type of heat exchanger is better suited for utilizing the waste heat. That is considering just the heat-recovery problem by itself. Admittedly, the metallic recuperator cannot go above a preheat of 800–850° C., but the saving obtainable by increasing the air preheat beyond this is comparatively small. On the other hand, with the metallic recuperator, the complete installation of furnace, burners, flues, and heat exchanger can be made more compact, particularly in contrast to the installations using regenerators. This compactness results in smaller overall radiation losses. There is also greater accuracy in maintaining the air/fuel ratio. With the higher combustion-air pressure available, good mixing burners can be used, thus ensuring a uniform furnace atmosphere, together with furnace-gas recirculation. In the majority of cases these advantages will give a better overall fuel economy.

The effect of furnace radiation losses on fuel consumption is high in the case of the open-hearth furnace. Even towards the end of the heat, when the effective thermal work of the furnace is practically nil, an appreciable amount of fuel is required to keep the furnace at temperature. With a one-way fired system, with a metallic recuperator, the total area of the high-temperature section of the furnace installation could be reduced. The temperature of the flue gas entering the waste-heat boilers would be higher than in the case of regenerators, but the final flue-gas exit temperature would be the same; and because the irrecoverable radiation losses of the furnace system have been reduced, the overall heat utilization would be better.

CORRESPONDENCE

Mr. **R. Hallam** (Newton, Chambers and Co., Ltd.) wrote: In Mr. Escher's paper, a trip mechanism is described by means of which the expansion of the recuperator shell is utilized to prevent overheating of the shell at the hot-gas end. Would it not be more direct to measure the temperature of the gases entering the recuperator and to control directly from that? I would also suggest that the total expansion of a long tube having a temperature gradient along its length is a function of the mean temperature of the tube, and does not, therefore, give an accurate indication of the temperature condition at the hot end.

Mr. Escher mentioned that, with fuel-gas preheats of up to 500° C., no carbon deposition or carbon monoxide attack on the metal had been experienced, and he suggested that future gas preheats of up to 600° C. could be achieved. Does he anticipate carbon troubles at the higher temperatures and will any steps be taken to limit the metal temperature on this account?

I was interested to see that swirlers and fins are utilized in the cooler sections of this recuperator to capture convective heat and so counteract the loss in radiant heat. However, I would like to know Mr. Escher's views on the gas temperature at which it is desirable to introduce this extended heating surface and additional turbulence.

On the question of steam-raising *versus* recuperation, there is no relationship between the furnace loading and the demand for steam, except where they both happen to be fairly constant, as in certain units outlined in the paper. It is suggested, therefore, that the adoption of recuperation achieves a self-contained unit of plant with

greater flexibility and ease of control. With correct design there is always a use for the preheated air leaving the recuperator.

I was most interested in the details given in Clift and Knight's Table V, which compares various schemes of waste-heat boilers and recuperators. I would suggest, however, that the authors' estimates of fuel savings by recuperation are extremely low. With 575° C. and 500° C. air preheat, and allowing, say, 10% cold air for atomization of the oil, the saving due to the recuperators would be about 23% and 21%, respectively, compared with figures of 14·6% and 11% derived from Table V. If the higher figures for fuel saving are used, the figures for net fuel consumption per hour given in the last column would be (reading down the column): 630, 340, 520, and 390 gal. The picture is then quite different, Alternative 2*a* being the most attractive from a thermal standpoint.

No ordinary cast-iron tubes are used in the recuperator, shown in Clift and Knight's Fig. 6, since both the bottom two banks of tubes were supplied in heat-resisting cast iron.

AUTHORS' REPLIES TO CORRESPONDENCE

Mr. Escher wrote in reply : Mr. Hallam suggests that the temperature measurement of the gases entering the recuperator be used to control the means of preventing overheating. This method is reasonably safe when the inlet temperature is so controlled that it does not exceed the maximum allowable working temperature of the recuperator metal. When the inlet temperature is much higher, however, the method would not be sufficiently reliable, as there are many factors that affect the relationship between inlet gas temperature and recuperator metal temperature (flue-gas velocities, air velocities, secondary combustion, radiation from flues, dust deposition on surfaces).

The method utilizing the direct thermal expansion of the heating surface is not affected by such factors, but the question arises of whether the mean temperature or expansion of the recuperator bears a definite relationship to the maximum recuperator temperature. The tabulation below shows (for a medium-length parallel-flow unit) that the mean shell temperature rises faster than the maximum shell temperature with increasing temperature level and thus provides additional accuracy of control in the dangerous temperature range.

	Air Preheat, °C.	Mean Shell Temp., °C.	Max. Shell Temp., °C.	Ratio of Max. to Mean Shell Temperature
Normal condition	675	660	795	1·20
Max. temp. condition	840	775	875	1·13

In long recuperators working with counterflow, the expansion of the hot end only has been used on some installations. In practice, this direct method has proved to be very effective and reliable. It does not involve the installation of expensive instruments and controls, and it requires practically no maintenance, an important advantage for small installations.

In regard to troubles that may be anticipated with preheating fuel gases to 600° C., I do not expect any, and I have dealt with this subject in some detail in the introduction of the paper and subsequent discussion.

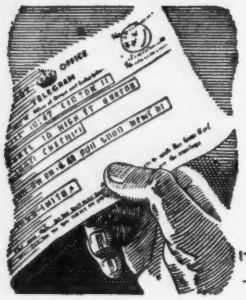
The third point raised by Mr. Hallam, on swirlers and fins, is not easy to answer, as there are many factors that have a bearing on their application. Welded-on mild-steel fins have been used on several recuperators, and their application is confined to flue-gas temperatures of about 650° C. (max.). Swirlers, on the other hand, can be used for much higher flue-gas temperatures.

Mr. Clift and **Mr. Knight** wrote in reply : We were interested in Mr. Hallam's estimates of fuel savings, which he has worked out from the information given in Table V of our paper, where various schemes of waste-heat boilers and recuperators are compared. It would appear, however, that Mr. Hallam has made some basic assumptions about quantities of air, which are not in line with those used by us in our estimates.

When we were considering these schemes, we based them (for several reasons) on the use of low-pressure oil burners, and worked out our estimates of fuel saving on a figure of 150 cu. ft. of preheated secondary air per lb. of fuel. Mr. Hallam's estimates are based on the use of 10% of cold air for atomization ; this would obviously mean the use of medium-pressure burners, which, for various reasons, we did not want.

We would, however, like to point out that even if his basis for estimating purposes is accepted Mr. Hallam has not completed his calculations, in that he has ignored the effect of the lower fuel consumption at the furnace on the steam-raising in the waste-heat boiler, and hence the decreased saving that is possible there. If due cognizance is taken of this effect, it will be found that the adjusted net fuel-consumption figures will be about 630, 390, 550, and 390 gal./hr. The general picture will, therefore, be virtually unchanged.

There is one point arising from Mr. Turner's reference to the change from regenerators to recuperators owing to difficulties in obtaining satisfactory refractory material. Mr. Turner appears to have misunderstood us, as we have not stated this, either in the paper or during the discussion. In fact, we agree with him that regenerator brickwork does not give rise to difficulties and, indeed, is one of the attractions with this type of waste-heat recovery equipment, as it leads to robust design and reliability in operation. It is often the site considerations, where heavy mill machinery makes it difficult to install regenerators, that determine the choice of recuperators.



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

The President

At the Annual General Meeting of the Institute, held on 30th April–1st May, Mr. James Mitchell, C.B.E., a Managing Director of Stewarts and Lloyds, Ltd., was inducted as President for the session 1953–54 by the retiring President, Captain H. Leighton Davies. A portrait and biography of Mr. Mitchell appear as a frontispiece to this issue.

Changes on Council

The following have accepted invitations to serve as Honorary Members of Council during their periods of Office:

Professor F. C. THOMPSON, President of the Institute of Metals

Mr. A. W. SHORE, President of the Staffordshire Iron and Steel Institute

Mr. A. McKENDRICK, President of the West of Scotland Iron and Steel Institute.

Autumn General Meeting, 1953

The **Autumn General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, during the second half of **November, 1953.**

Special Report on Ingot Surface Defects

Further copies of Special Report No. 44, "*Surface Defects in Ingots and Their Products* (*Recommended Definitions*)", are now available and can be supplied at £1 5*s*. 0*d*. per copy (Members 15*s*.).

Indexes and Binding Cases for the Monthly Journal

Further copies of the index to vols. 155, 156, and 157 of the *Journal* are now available and can be supplied free of charge on request. A limited number of binding cases for these volumes is also available and will be supplied to Members free of charge on request.

NEWS OF MEMBERS

▶ Mr. H. BAKER has left J. Booth and Bros., Rodley, to take up an appointment with Steel Plant Auxiliaries Ltd., Sheffield.

▶ Mr. B. G. BALDWIN has been awarded the Ph.D. degree of the University of London.

▶ Mr. A. R. G. BROWN has left the British Iron and Steel Research Association to take up the appointment of Senior Scientific Officer at the Royal Aircraft Establishment, Farnborough.

▶ Dr. G. P. CONTRACTOR has relinquished his position as Acting Director of the National Metallurgical Laboratory, Indian Council of Scientific and Industrial Research. He will leave India in August and will visit the U.K. on his way to Canada.

▶ Dr. E. C. ELLWOOD has given up the post of Senior Lecturer in Metallurgy at King's College, University of Durham, to become Chief Metallurgist to the Tin Research Institute, Perivale.

▶ Mr. H. GIBSON has left Messrs. Buch and Co., Ltd., Howrah, Bengal, and has returned to England.

▶ Mr. K. KORNFELD has left the Fairey Aviation Co., Ltd., and is now residing in Montreal, Canada.

▶ Dr. A. LATIN has left British Insulated Callender's Cables, Ltd., to become Head of the Department of Metallurgy and Chemistry of the National Coal Board, Isleworth.

▶ Dr. O. T. MARZKE, superintendent of the Metallurgy Division at the Naval Research Laboratory, Washington, U.S.A., has been appointed consultant to the Director of Research at the Laboratory in the fields of chemistry, electricity, mechanics, and metallurgy.

▶ Mr. P. S. MATHUR has left the Blast-Furnace Department of Dortmund-Hörde-Hüttenunion A.G., and has joined the Blast-Furnace Department of Messrs. Hochofenwerk Lübeck A.G., West Germany, for six months' specialized training.

▶ Mr. J. A. MATTHEWS, of the Eagle Star Insurance Co., Ltd., has been made a Liveryman of the Worshipful Company of Farriers and a Freeman of the City of London.

▶ Mr. W. J. NEAGLE-JONES has left Teddington Controls, Ltd., to take up the appointment of Chief Metallurgist with the Brockworth Engineering Co., Ltd., Hucclecote, Gloucester.

▶ Mr. J. G. PARR has given up the post of Lecturer in Metallurgy at the University of Liverpool, and now holds a Post-Doctorate Research Fellowship with the British Columbia Research Council, Vancouver.

▶ Mr. A. S. PEACOCK has transferred from the Renfrew Works of Babcock and Wilcox, Ltd., to their London Office, where he holds the post of Executive Assistant to the Managing Director.

▶ Mr. E. W. ROBERTS has taken up an appointment with the Bahrein Petroleum Co., Ltd., Awali, Persian Gulf.

▶ Mr. R. TATE has taken up the appointment of Defence Research Technical Officer with the Defence Research Board of Canada.

▶ Dr. P. VAJRAGUPTA has transferred from the Government Mines Department to the Department of Metallurgical Works of the Ministry of Industry, Bangkok, Siam.

▶ Mr. J. WILLIAMSON has left Wm. Jessop and Sons Ltd., to take up the appointment of Technical Manager with Messrs. Spear and Jackson, Ltd., Sheffield.

▶ Mr. F. WOODIFIELD has been appointed Assistant Managing Director of the Park Gate Iron and Steel Co., Ltd.

Obituary

Dr. Ing. G. ASBECK, of Düsseldorf-Rath, on 1st January, 1953. Dr. Asbeck started his career at Maschinenfabrik Sack as Chief Engineer, and later became Director and sole Manager. He received the Carl Lueg Medal of the Verein deutscher Eisenhüttenleute in 1952, and on 6th January, 1953, he was to have received the Grand Cross of the Government of the German Federation for his distinguished services.

Mr. S. D. ORR, of Buxton, Derbyshire, on 30th August, 1952.

CONTRIBUTORS TO THE JOURNAL

G. Coombes, B.Sc., Ph.D., A.I.M.—Research and Development Metallurgist, Edward Curran Engineering, Ltd., Cardiff.

Dr. Coombes was born in Tredegar, Monmouthshire, in 1927. He was educated at Scunthorpe Grammar School, and in 1945 was awarded a State Bursary and a Lindsey Senior Scholarship to the University College of South Wales and Monmouthshire, where he graduated with 1st Class Honours in Metallurgy. From 1948 until he took up his present appointment last year, Dr. Coombes continued his studies at the University College as a bursar of the British Iron and Steel Research Association, and was awarded the Ph.D. degree of the University of Wales in 1952 for his work on the strain ageing of mild steels.

W. Steven, Ph.D., B.Sc., A.R.T.C., F.I.M.—In charge of steel and cast-iron research at the Birmingham Laboratory of the Mond Nickel Co., Ltd.

Dr. Steven was born at Glasgow in 1917. He was educated at Glasgow University, where in 1939 he graduated with 1st Class Honours and was awarded the Walter Duncan Research Scholarship. Four years later he was awarded the Ph.D. degree of the University. In 1943 he joined William Jessop and Sons, Ltd., where he worked as a research metallurgist until he took up his present appointment in 1948.

G. Mayer, B.Sc., A.I.M.—Research Metallurgist at the Birmingham Laboratory of the Mond Nickel Co., Ltd.

Mr. Mayer was born in 1917, and was educated at Wellington High School and at the University of Birmingham, where he graduated with 1st Class Honours in Metallurgy in 1939. He took up his present appointment in the same year.

W. Steven

G. Mayer

IRON AND STEEL ENGINEERS GROUP

Ablett Prize

On the recommendation of the Engineering Committee, it has been decided that the conditions governing the award of the Ablett Prize should be as follows :

(1) The Prize should be given for the best paper received each year on a subject associated with iron and steel works engineering

(2) The winning paper must be suitable and available for publication in the *Journal*

(3) The author should be below the age of 35

(4) The author need not be a Member of The Iron and Steel Institute.

Members are asked to make these details known to members of their organizations. Suitable papers are invited, and they should be addressed to the Secretary, 4 Grosvenor Gardens, London, S.W.1.

NEWS OF SCIENCE AND INDUSTRY

Metallurgical Applications of Thermodynamics

The Department of Extra Mural Studies of Birmingham University will hold a Week-end School on the subject of "The Metallurgical Applications of Thermodynamics," at the University, Edmund Street, Birmingham, on Friday and Saturday, 8th and 9th May, 1953.

The object of the school is to indicate the range of application of thermodynamics to both physical and process metallurgy and to show how the fundamental relationships in thermodynamics can be used in the design and study of metallurgical processes. The series of lectures will develop the subject from first principles and will emphasize the practical rather than the formal approach to the subject. The methods of statistical mechanics will also be used both to clarify the physical principles on which thermodynamics is based and to evaluate the thermodynamic functions.

Enquiries should be made to the Director of Extra Mural Studies, the University, Edmund Street, Birmingham, 3.

Conference on the Cold Extrusion of Steel

The Sheet and Strip Metal Users' Technical Association has arranged a two-day Conference on the Cold Extrusion of Steel, to be held on 12th and 13th May, 1953, in the main hall of the Royal Empire Society, Northumberland Avenue, London, W.C.2. Various problems associated with cold extrusion of steel will be dealt with in a range of papers on subjects including the principles and practice of cold extrusion, the use of presses, metallurgical requirements, and lubrication. Full details and application forms for tickets are obtainable from the Honorary Secretary of the Association, 49 Wellington Street, Strand, London, W.C.2.

Conference on Heat-Treatment Practice

The British Iron and Steel Research Association has arranged a Conference on Heat-Treatment Practice, to be held at Ashorne Hill, Leamington Spa, from 15th to 17th June, 1953. The conference, which is being organized by the Metallurgy (General) Division of B.I.S.R.A., will include papers and discussion on the heat-treatment of engineering steels, large forgings, and sections ; surface treatments ; isothermal heat-treatment ; and temperature measurement and control. Further particulars may be obtained from Mr. A. M. Sage, British Iron and Steel Research Association, 11 Park Lane, London, W.1.

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee invites applications for the award of Mond Nickel Fellowships for the year 1953. Awards will be made to selected applicants of British nationality, educated to University degree or similar standard, although not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments: they will normally take the form of travelling Fellowships—awards for training at University may be made in special circumstances. There are no age limits although awards will seldom be given to persons over 35 years of age. Each Fellowship will occupy one full working year. The Committee hope to award up to five Fellowships each year, of an average value of £900 to £1200 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects:

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons qualified in Sciences other than Metallurgy may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications, and previous career. Full particulars and forms of application can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1.

Completed application forms will be required to reach the Secretary of the Committee not later than 1st June, 1953.

Full-Time University Courses in Science

Since the war, full-time courses for Internal Students of the University of London have been developed at the Sir John Cass College. Most students join the courses immediately after leaving school, and others enter from industry after they have completed the initial stages of their degree course or professional training by part-time study.

The courses are arranged under recognized teachers of the University of London as a preparation for Internal Special degrees, including Chemistry, Mathematics, Metallurgy, and Physics. Full-time courses are held for the Associateship of the Royal Institute of Chemistry, for the Graduateship of the Institute of Physics, and for the Licentiateship and Associateship of the Institution of Metallurgists.

Applications for admission in September, 1953, are now invited, and the Principal, Dr. A. M. Ward, D.Sc., F.R.I.C., will be glad to supply further information.

British Steel Castings Research Association

The Research and Development Division of the British Steel Founders' Association, established in 1949, will in future be known as the British Steel Castings Research Association. Mr. F. N. Lloyd is the first Chairman of the Council, and Mr. J. F. B. Jackson will continue to serve as Director of Research. For further particulars *see* p. 16 of this issue.

Changes of Address

JOHN LE BOUTILLIER LTD. have moved to new offices in British Columbia House, 3 Regent Street, London, S.W.1. (Tel. Trafalgar 5005).

The address of the MARKET DEVELOPMENT DEPARTMENT of the BRITISH IRON AND STEEL FEDERATION is now Abbey House, Suite 112–118, Victoria Street, London, S.W.1. (Tel. Whitehall 1030).

Messrs. HONEYWELL-BROWN LTD., Greenford, Middx., have opened a branch office at 67 Exchange Buildings, Stephenson Place, Birmingham, 2. (Tel. Midland 0857).

Industrial Publications Received

▶ Lift-Out, Tilting, and Bale-Out Crucible Furnaces—Brochures *FD* 5, *FD* 10, and *FD* 14, The Morgan Crucible Company, Ltd.

▶ X-ray Accessories—Solus-Schall Ltd.

▶ Automatic Control Applied to Spreader Stoker-fired Boilers—Catalogue No. E1022, Bailey Meters and Controls, Ltd.

▶ Philips Industrial Products—Catalogue No. PD3444, Philips Electrical Ltd.

▶ Messrs Stewarts and Lloyds, Ltd., have issued a pocket-sized chart, showing the discharge from galvanized and bitumen-lined steel tubes.

DIARY

7th May—LEEDS METALLURGICAL SOCIETY—Annual General Meeting and Junior Members' Papers—Chemistry Department, The University, Leeds 2, 7.0 P.M.

11th–14th May—IRON AND STEEL ENGINEERS GROUP—Meeting of Junior Engineers and Operators—Ashorne Hill, Leamington Spa.

12th–13th May—SHEET AND STRIP METAL USERS TECHNICAL ASSOCIATION—Conference on the Cold Extrusion of Steel—Royal Empire Society, Northumberland Avenue, London, W.C.2.

13th May—SOCIETY OF CHEMICAL INDUSTRY (Corrosion Group)—Annual General Meeting—Burlington House, Piccadilly, London, W.1. 6.30 P.M.

15th May—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Conference on Brittle Fracture in Steel—39, Elmbank Crescent, Glasgow, 10.0 A.M.

TRANSLATION SERVICE

(The previous announcement was made in the April, 1953, issue of the *Journal*, p. 434).

TRANSLATION IN COURSE OF PREPARATION

(German). E. SENFTER : "The Treatment of Pig Iron and Steel with Slags as a Means of Improving the Steel." (*Archiv für das Eisenhüttenwesen*, 1953, vol. 24, Jan./Feb., pp. 1-10).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s*. for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUESTS—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

ABSTRACTS AND BOOK NOTICES

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MINERAL RESOURCES

Wartime Investigations into the Haematite and Manganese Ore Resources of Great Britain and Northern Ireland. A. W. Groves. (*Ministry of Supply, Monograph* 20·703, 1952).

Contributions to the Knowledge of the Mineral Wealth of the Dominican Republic. W. Bartels. (*Metall u. Erz*, 1941, **38**, Feb., No. 3, 45–50; Feb., No. 4, 75–78).—L.H.

Contribution to the Knowledge of the Mineral Wealth of North Borneo. F. H. Stang. (*Metall u. Erz*, 1942, **39**, June, No. 12, 217–221). A geographical survey is given of the mineral deposits of North Borneo, with the history of their discovery. Chrome ore deposits are widespread, and tests have shown as much as 53·6% of chromium oxide. The location of important iron ore deposits is given, with up to 63% iron and low in sulphur. Manganese ore (Mn 60%) is found in the Darvel bay area.—L. H.

Gravity Investigations in the Iron River–Crystal Falls Mining District of Michigan. L. O. Bacon and D. O. Wyble. (*Min. Eng.*, 1952, **4**, Oct., 973–979). Details of the method, and field data, are presented for a gravity survey of approx. 800 sq. miles in Iron County, using the Worden Gravimeter No. 28. The results agreed reasonably well with bore hole information.

Mining Industry of the German Protectorates in Africa and in the South Seas, with Special Reference to Ore Mining. P. Range. (*Metall u. Erz*, 1941, **38**, May, No. 10, 213–221).

The Manganese and Iron Ore Deposits of Postmasburg in the Southern Kalahari. M. Richter. (*Metall u. Erz*, 1941, **38**, May, No. 10, 225–230). The exact geographical location of the West Griqualand and Bechuanaland iron and manganese ore deposits is given, followed by a geological description. The manganese ore is extensive and of very high quality.

The Importance of the Mineral Resources of Africa for the European Metal Economy. R. Dobransky. (*Metall u. Erz*, 1941, **38**, May, No. 10, 244–258). The importance to European economy of the exploitation of African mineral resources is emphasized. Tables are given showing the exports of manganese ore from 1929 to 1938, from the Gold Coast, Union of S. Africa, Algeria and the Belgian Congo. The Egyptian sources are also described and the iron ore resources of Africa are outlined.—L. H.

Ore Deposits in Southern Morocco. H. M. E. Schürmann and W. Schutz. (*Metall u. Erz*, 1942, **39**, Oct., No. 20, 363–367). The authors first outline the history of the development of the area, then deal with the location and nature of the mineral deposits. The most important deposits are in the Tangirfa valley district, where the sandstone contains high-grade brown ore in three main deposits; in the same district are poorer grades of red ore.—L. H.

The Hematite and Magnetite Resources of Melilla (Spanish Morocco). H. Quiring. (*Glückauf*, 1942, **78**, June 6, 326–328, June 13, 339–341). The output of red and magnetic iron ores from 1920 to 1938 is given together with the geographical location of the various ores in Spanish Morocco.—R. J. W.

ORES—MINING AND TREATMENT

The Open-Cast Working of Jurassic Iron Ores in the Corby District, England. H. Fischer. (*Berg- hüttenmänn. Monatsh.*, 1952, **97**, July, 127–130).

Influence of the Material and the Profile Size in the Load Bearing Capacity of Gallery Arches. R. Hünlich. (*Glückauf*, 1952, **88**, Dec. 20, 1259–1263). In view of the need for greater strength in steel pit supports, experiments were carried out with a variety of steels on the bending and tensile yield points, and their relation to the profiles of the structures. The ratio n of the bending to the tensile yield point was almost independent of the profile, but increased with increasing yield point. Thus an economy could be effected by a profile reduction and by employing high-duty steels in parts subject to bending stresses.—L. H.

Investigation of Effects of Weathering on Sulphide Minerals and Ores. S. Bergenfelt. (*Jernkontorets Ann.*, 1952, **136**, 10, 429–438). [In Swedish]. A brief account is given of oxidizing reactions in ordinary sulphide minerals. Tests to establish effects of weathering on ores included leaching tests and analyses of mine waters. The active influence of iron pyrites on ore oxidation can be ascribed to the formation of H_2SO_4. Where pyrites are predominant, acid mine water results, as at Boliden and Kristineberg. Where pyrite content is low oxidation is much slower.—G. G. K.

The Mechanical Loaders of Gewerkschaft Eisenhütte Westfalia, Lüken, and Their Possible Applications, in Particular in Ore Mining. F. Radtke. (*Metall u. Erz*, 1942, **39**, Apr., No. 8, 137–143). This article first points out the need for mechanical loading of ores if large quantities are to be handled, and lists the necessary properties of such a machine: these are simple, strong construction, avoiding complicated and sensitive parts, ease of handling by unskilled workers, and convenience of transport.—L. H.

X-Ray Diffraction Study of Limonite. D. R. Dasgupta and J. C. Maitra. (*Acta Crystallographica*, 1952, **5**, Nov. 10, 851–852). [In English]. Spacings and intensities of powder lines of a sample of natural limonite from Gosalpur (Jubbulpur) are given. It is concluded that natural limonite is crystalline though incapable of forming single crystals of appreciable size.—T. E. D.

Experiences from the Installation of a Loading Elevator in a Siegerland Spathic Ironstone Mine. G. Schröder. (*Metall u. Erz*, 1942, **39**, May, No. 9, 163–165).

New Grinding Theory Aids Equipment Selection. F. C. Bond. (*Chem. Eng.*, 1952, **59**, Oct., 169–171). A new theory of size reduction is developed to replace the older theories of Rittinger and Kick. According to this theory, the work necessary to break a ton of rock is inversely proportional to the diameter of the product particles. An illustrative example is calculated.—T. E. D.

New Methods of Filtration in Beneficiation Plants. R. Wüster. (*Metall u. Erz*, 1940, **37**, Dec., No. 23, 469–473; Dec., No. 24, 490–493). The article first outlines the advantages of dehydration of ore and coal fines, and describes some early types of filter. The increasing use of low-grade and complex ores has led to a finer grinding, and hence to the need for improved filtering techniques. Modern types of plant are described and illustrated.—L. H.

Recent Results of Electrostatic Beneficiation. A. Stieler. (*Metall u. Erz*, 1941, **38**, Nov., No. 21, 457–462). In the section of this article dealing with iron ores, the author describes the results of laboratory scale experiments with a brown iron ore. A previously roasted ore gives the best results. As an example, an electrostatically concentrated roasted ore with 24% Fe produced a concentrate of more than 44% Fe; at the same time the silica content was reduced from 22% to about 12%.—L. H.

Possibilities of Concentrating Lorraine Ores, and High Intensity Magnetic Separation. L. Coche, D. Dastillon, and L. Wahl. (*Inst. Hierro Acero*, 1952, **5**, May, 476–512). [In Spanish]. The authors give an account of the incomplete French work on the beneficiation and magnetic separation of Lorraine iron ores. Full details are contained in the records at the IRSID research station at Saulnes. The majority of Lorraine ores could not be separated by any physical process under present economic conditions. (42 diagrams).

A Contribution to the Study of the Beneficiation of Jacutinga Iron Ore for Blast-Furnaces. A. H. da Silveira Feijo. (*Bol. INT.*, 1950, **1**, Sept., 13–22). [In Portuguese]. Jacutinga iron ore contains about 68% Fe and 0·015 to 0·40% P; it is of a powdery nature. The author describes the experience obtained in compression tests and in the sintering of (*a*) pure Jacutinga ore, and (*b*) mixtures of this ore with cement, clay, and blast-furnace slag.—R. S.

Factors in the Economics of Heat-Treated Taconites. W. Mitchell, jun., C. L. Sollenberger, and F. F. Miskell. (*Min. Eng.*, 1952, **4**, Oct., 962–967). Comprehensive test data, and an economic analysis of commercial applications, are presented for various types of heat-treatment on Minnesota magnetic taconites before rod-milling for concentration. Heat-treatment can reduce grinding media wear, and improve iron recovery by oxidation of limonite. Optimum results were obtained by kiln roasting to 1800° F., followed by water quenching. (11 references).—K. E. J.

Taconite: Beneficiation Projects in U.S.A. (*Iron Steel*, 1952, **25**, Sept., 416–417). The rapid depletion of the Mesabi and Lake Superior ores in the U.S.A. has led to the development of a process for beneficiating the vast taconite deposits. The method and its development are briefly described, and plans for full-scale commercial plants are outlined.—G. F.

Microstructures in Iron Ore Pellets. S. R. B. Cooke and T. E. Ban. (*Min. Eng.*, 1952, **4**, Nov., 1053–1058). Results of studies of the mineralogy, structure, and strength of laboratory iron ore (mainly magnetite) pellets are presented. Pellets were fired in air and neutral atmospheres at various temperatures. Pilot-plant pellets compared closely with one air-fired series. The stages of pelletization are visualized as: (1) Oxidation of slime magnetite in the shell; (2) oxidation of coarser shell magnetite; (3) completion of strong shell; (4) magnetite network forms in core; (5) plastic slag matrix forms at 1100–1200° C., and magnetite recrystallizes in core, with some rearrangement of pore space; and (6) substantial oxidation of magnetite in core.—K. E. J.

Eliminating Hand Picking at the Mt. Hope Mine. H. Schwellenbach. (*Min. Eng.*, 1952, **4**, Oct., 950–951). Labour shortages, rising wages, and increases in moisture and fines content have necessitated changes in the flowsheet of concentrate ore for open-hearth use. A second screening at $\frac{3}{8}$ in. eliminated adhering magnetite fines from the large lumps. A high-intensity magnetic cobber gave results comparable with the picking belt for cleaning lumps over 2 in.—K. E. J.

Beneficiation of Low-Grade Chrome Ore from Dodkanya (Mysore). P. I. A. Narayanan and G. P. Mathur. (*J. Sci. Indust. Res.*, 1952, **11A**, May, 202–204). A good grade chromite assaying 47·5% Cr_2O_3, 23·51% FeO, with 70·6% chromite recovery is obtained by tabling a < 100-mesh feed. Electromagnetic separation, Humphrey's spiral, the Wifley table, and selective flotation were unsatisfactory.—E. T. L.

FUEL—PREPARATION, PROPERTIES AND USES

Remarks on the Calculation of Combustion. U. T. Boedewadt and R. Engel. (*Recherche Aéronautique*, 1952, Mar.–Apr., 19–30). Methods of establishing an energy balance in combustion systems are considered. The part played by the individual constituents and the theoretical performance of any combination of oxidant and fuel are examined. Enthalpy/temperature relations are represented graphically.—T. E. D.

Flame Radiation Research. M. W. Thring. (*Indust. Heating*, 1952, **19**, Sept., 1602–1612, 1724–1726). The investigations of an international Flame Radiation Committee working in Holland are described. Trials carried out on the experimental furnace are divided into two parts, namely, performance trials and combustion mechanism trials. The object of the latter trials is to investigate the effects on the fuel as it passes through a flame in order to understand the fundamental phenomena which can then be investigated in the laboratory. The results of the first performance trials showed that, within ± 10%, the emissivity, flame temperature, flame width, and transverse radiation can be represented as a function of distance along the flame. The results are expressed in curves which can be applied to other hot wall flames of similar fuels. Peak radiation was 17% higher with pitch creosote than with oil, and 8% higher with air atomization than with steam.

Numerical Solution of Unsteady-State Heat Conduction Problems by the Method of Crank and Nicolson. G. Leppert. (*J. Amer. Soc. Naval Eng.*, 1952, **64**, Aug., 611–619). The authors review a new mathematical method proposed by Crank and Nicolson for the solution of partial differential equations of the heat conduction type, and this is compared with the Emmons-Dusinberre and the Binder-Schmidt methods.—J. C. B.

Performance of Finned Tubes in Shell-and-Tube Heat Exchangers. R. B. Williams and D. L. Katz. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, Nov., 1307–1320). Heat-transfer measurements have been made on three pairs of tube bundles, plain tubes in one bundle and finned in the other. Measurements were made for water, lubricating oil, and glycerine on the shell side using several temperature levels and differences.—D. H.

Refractive Indices of Vitrain as an Index of Rank of Coal. K. C. Lahiri and T. N. Basu. (*J. Sci. Indust. Res.*, 1952, **11**, Nov., B486–490).

Coal Preparation. A. Grounds. (*Colliery Guardian*, 1952, **185**, Dec. 23, 767–772). The main functions of coal cleaning in the past and at the present time are discussed. Future trends in the use of coal cleaning are outlined, and methods available are mentioned.—T. E. D.

Application of Coarse Coal Magnetite Separators in an Existing Circuit. V. D. Hanson, W. K. Heinlein, and J. M. Vonfeld. (*Min. Eng.*, 1952, **4**, Oct., 983–988). Details are given of pilot and production scale operation of overfeed drum-type separators using a suspension of magnetite in water as the separating medium: these have replaced hand picking in the preparation plant of the Pittsburgh Coal Co.

New Methods of Preparing Coal in Heavy Liquids. E. Trümpelmann. (*Glückauf*, 1943, **79**, Nov. 27, 529–537; Dec. 11, 559–566). Methods for the rapid change in bath density in the sink–swim beneficiation of coal using heavy liquids are first given, together with the advantages of the method. Automatic bath purification and multiple baths with zones of different densities are then described.—R. J. W.

Tests with the Electrostatic Preparation of Coal Dust. F. L. Kühlwein. (*Glückauf*, 1941, **77**, Feb. 1, 69–80). Dry fine-grain beneficiation as opposed to flotation is considered with reference to their relative merits in the beneficiation during coal washing and refinement. Separation with rollers is also considered. The application of the electrostatic beneficiation of coal dust depends on the success of the fine sifting, which itself is dependent upon thermal drying. A large-scale experiment with 20 different types of coal dust from coking coal is described.—R. J. W.

Electrostatic Preparation of Fine-Grained Bituminous Coal and the Production of Coal and Coke with Low and Very Low Ash Contents. H. Niggemann. (*Glückauf*, 1941, **77**, Feb. 1, 80–88). An experimental arrangement for the electrostatic beneficiation of coal dust, and its mode of action are described. Results are given for the electrostatic beneficiation of pulverized ore and coal, and for the production of coke and coal with very low ash contents by this method. The advantages of producing dry coking coal and dry intermediate products with the consequent elimination of slime are stressed.—R. J. W.

A Costing Flow Sheet for Beneficiation Installations. S. Flehmig. (*Glückauf*, 1952, **88**, Nov. 22, 1149–1154). A costing system is described and illustrated in detail by an application to a coal washing plant. The mean value of the specific expenditures of new construction projects and existing plant are multiplied by the nominal throughput to give the absolute cost. The separate absolute costs of the different size gradings are obtained from a quantity flow-sheet, from which the costing flow-sheet is constructed.—L. H.

Determination of the Yield in Coal Beneficiation. H. Paul and C. Kühn. (*Glückauf*, 1952, **88**, Nov. 22, 1155–1161). The author describes the calculation of the yield from the chemical and physical constitution of the charge and the product, by means of two- and three-product formulæ. Applications and limitations of the method are discussed, and a number of practical examples are given.—L. H.

The Swelling of Bituminous Coals During Carbonization. K. Gieseler. (*Glückauf*, 1941, **77**, May 24, 309–319; May 31, 328–332). A device for measuring swelling pressures, due to Hofmeister, is first described and followed by a description of the Waldenburger muffle tests. This instrument has been to some extent superseded by a new apparatus incorporating dual movable furnaces. The coking of a cross-section of a coal layer is described in terms of pressure and shrinkage under various conditions, including double coking.—R. J. W.

The Manufacture of Coke in the Electric Furnace. A. Paoloni. (*J. Four. Elect.*, 1952, **61**, May–June, 83–86; July–Aug., 102–103). After reviewing some of the earlier furnace designs the Stevens furnace at Detroit is discussed. The author considers that less than 50% of the sensible heat of the coke can be used to preheat the coal and to reduce the electrical energy required to about 250 kWh./ton of coal.

The History of the Development of Coke-Oven Operation, Especially that of Coke-Oven Laboratories of the Hanover and Hannibal Collieries of Fried. Krupp A.-G., at Bochum-Hordel. F. Lange and W. Brösse. (*Glückauf*, 1942, **78**, Aug. 1, 444–447). The development of the coke-oven operation over the last 70 years is traced.—R. J. W.

Coking with Internal Suction through the Oven Doors. H. Niggemann. (*Glückauf*, 1943, **79**, Jan. 2, 5–9). Experiments are discussed in which it was established that, by coking with an elaborate method of internal suction through the oven doors instead of a comparatively simple one, the recovery of the valuable low temperature retort oils was increased from 20 to 30%. The properties of these oils and their possible uses, dependent upon the composition, the high heat content, and the useful possibilities of the gases are briefly described. Working instructions are given for the various methods.

Fundamental Circulation Techniques of Coke Oven Heating. W. Litterscheidt. (*Glückauf*, 1952, **88**, Nov. 22, 1137–1149). Designs of coke-oven heating and regenerator systems have been established more or less empirically; the regulating gear does not always ensure ideal distribution of the heating and waste gases without lengthy tests, and a change from lean to rich gas and *vice versa* is another source of variation. Various heating and regenerating systems, with a view to establishing correct design in each case, are surveyed.—L. H.

The Problem of the Special Regulation of the Temperatures of Gas Collecting Chambers. W. Stäckel and G. Lorenzen. (*Glückauf*, 1942, **78**, Dec. 26, 773–782). The importance of the effect of the temperature of the gas-collecting chamber above the coke-ovens on the yield of by-products is pointed out, and the Otto compensation method of measuring and controlling this temperature is described.—R. A. R.

The Effect of Water Content of Coking Coal on the Coking Process. G. Blecher. (*Glückauf*, 1944, **80**, Apr. 1, 125–131). It is shown that a high and fluctuating moisture content in the coking coal has detrimental effects on its bulk density, coking behaviour, and heat consumption in coking. Efforts should be directed to reducing the moisture to 8 to 10% with fluctuations not exceeding $\pm$ 0·5%; this can only be done by keeping constant the grain size and distribution of coking coal. Examples of steps taken at coke-oven batteries which increased yields are cited.—R. A. R.

The Recovery of Some Waste Materials in Coke Oven Practice. C. Koeppel. (*Glückauf*, 1942, **78**, Sept. 12, 533–536). Plant is described for the decomposition of thick tar, for the utilization of saturator slime, the recovery of phenol from various parts of the process, and the recovery of naphthaline from the final cooler.—R. J. W.

Measures to Increase the Yield of By-Products During Coking. L. Nettlenbusch. (*Glückauf*, 1943, **79**, Jan. 16, 33–39). The usual methods of producing by-products are first reviewed and followed by a description of the physical-chemical processes that take place in a coke oven. A description of the new methods of increasing the output of the valuable by-products to a maximum independent of the coking time, is given.—R. J. W.

New Methods for the Wet Desulphurization of Coke-Oven Gas. A. van Ahlen. (*Glückauf*, 1941, **77**, Aug. 16, 481–487; Aug. 23, 493–501). The importance of desulphurization for industrial and communal gas plants is stressed. The economics of desulphurization are enhanced by the immediate production of elementary sulphur or H_2SO_4, made possible by the new methods described. Two main types of process have been developed: (*a*) The oxidation type, *e.g.*, the thylox method, and (*b*) hot activation processes, including the potash-pressure, the phosphate and organic methods. These are all discussed in detail.—R. J. W.

Practical Measures to Reduce the Consumption of Wash Oil and to Improve the Washing of Benzole. K. Brüggemann. (*Glückauf*, 1940, **76**, Apr. 13, 369–377). Several new ways of reducing the consumption of oil are described, especially the successful methods using an hydrogenated oil and a special wash oil. The advantages accruing from pressure oil washing are stressed. For normal tar wash oil, numerous recommendations are made, especially with regard to regeneration.—R. J. W.

The Oil Yield in Coking. W. Reerink. (*Glückauf*, 1942, **78**, Oct. 10, 597–605). After consideration of the various factors influencing the oil yield in coking, methods and proposals to increase this yield are discussed. They fall into two main groups. The first group entails drawing off the primarily formed low-temperature tar constituents through the oven cover or the doors. The second group consists of methods wherein the aim is to maintain favourable temperature conditions in the gas chambers.—R. J. W.

Developments and Knowledge in the Preparation of Distillation Gas from Coke Ovens. W. Gras. (*Glückauf*, 1942, **78**, Jan. 31, 57–61; Feb. 7, 73–76). The method of preparation of distillation gases in coke ovens, from the tar collecting mains to the remote gas connections, is described and the following processes detailed: (1) Tar separation; (2) gas cooling, washing the gas under normal and high pressures; (3) desulphurization with potash under pressure and with ammonia under normal pressure; and (4) the drying and measurement of the gas. Finally, the possible shortening of the path of the gas, using a by-product recovery plant, is briefly described from the viewpoint of gas storage.—R. J. W.

Investigations on the Influence of Chamber Wall Temperatures on the Yield and Quality of Hydrocarbons in the Coking Process. W. Gröbner and A. van Ahlen. (*Glückauf*, 1942, **78**, Apr. 11, 201–211). Numerous experiments are described to ascertain the dependence of the constancy and quality of hydrocarbons on the temperature in a selected works oven. The oven had three different temperature ranges and the time of coking and its effect on the yield of coke, gas, tar, benzol, and naphthaline were investigated. The hydrocarbon materials produced and their quality were observed. The effect of temperature on the rate of reaction is also considered.—R. J. W.

TEMPERATURE MEASUREMENT AND CONTROL

Automatic Glass Pens for Pyrometric Instruments. A. A. Nizovtsev. (*Zavodskaya Laboratoriya*, 1950, No. 6, 766). [In Russian]. A brief account is given of a glass and rubber pen of simple construction which has given satisfactory service in industrial temperature recorders.—S. K.

Multiple-Shielded High-Temperature Probes. E. M. Moffatt. (*SAE Quarterly Trans.*, 1952, **6**, Oct., 567–580). The measurement of gas temperatures of up to 1000° F., at velocities of up to 2000 ft./sec., is a difficult proposition because velocity,

radiation, and conduction errors become appreciable. High-temperature thermocouple probes incorporating several concentric guard rings surrounding the hot junction, have been designed and are described. These reduce, but cannot eliminate, the errors. The limitations of such probes and methods of calculating their errors under different operating conditions are discussed. (10 references).—P. M. C.

Roof Temperature Measurements on Open-Hearth and Electric Arc Furnaces with Photocell Pyrometers. K. Guthmann, P. E. Funke, W. Hunsinger, C. Kreutser, W. Keller, O. Stebel, and W. Wislicenus. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1418–1425). Results of experiments and works' tests in the optical determination of roof temperatures, especially with photocell pyrometers in open-hearth furnaces, are reported. These instruments permit continuous supervision of the roofs and thus contribute to enhanced refractory life and a better control of the steelmaking process.—J. P.

Study of Platinum/Platinum–Rhodium Thermocouples and Industrial Applications. M. Chaussain. (*Fonderie*, 1952, June, 2955–2970). The author surveys methods of inspecting and testing the platinum and platinum–rhodium wires. Applications to the measurement of liquid steel temperatures are described.—R. S.

Measuring the Temperature of Molten Metals. V. Sindelář. (*Hutnik* (Prague), 1952, **2**, 11, 243–247). [In Czech]. A description is given of existing methods and instruments used for measuring the temperature of molten metals. Contact thermocouples, optical and total-radiation pyrometers, as well as instruments based on photoelectric cells, are described.

REFRACTORY MATERIALS

On the Technology of the Graphite Crucible. W. Lex. (*Berg- hüttenmänn. Monatsh.*, 1952, **97**, June, 107–108). Methods of making graphite crucible for melting steels are considered, and the effects of various proportions of constituents on the length of their useful life in service are discussed. War-time methods of crucible production in Germany, using inferior local materials, and the properties of the crucibles obtained are surveyed.—P. F.

Adsorption of Water Vapor by Montmorillonite. I—Heat of Desorption and Application of BET Theory. R. W. Mooney, A. G. Keenan, and L. A. Wood. (*J. Amer. Chem. Soc.*, 1952, **74**, Mar. 22, 1367–1371).

Adsorption of Water Vapor by Montmorillonite. II—Effect of Exchangeable Ions and Lattice Swelling as Measured by X-Ray Diffraction. R. W. Mooney, A. G. Keenan, and L. A. Wood. (*J. Amer. Chem. Soc.*, 1952, **74**, Mar. 22, 1371–1374).

The Experimental Determination of the Surface Tension of Magnesium Oxide. G. Jura and C. W. Garland. (*J. Amer. Chem. Soc.*, 1952, **74**, Dec. 5, 6033–6034). A simple thermodynamic theory is presented which permits the determination of the surface tension, energy, and entropy of a solid. The necessary measurements are all calorimetric. Results are presented for magnesium oxide.—R. A. R.

Contribution to Knowledge of the Resistance of Sintered Alumina to Corrosion. G. Jaeger and R. Krasemann. (*Werkstoffe u. Korrosion*, 1952, **3**, Nov., 401–415). Sintered pure alumina has become an indispensable material for the manufacture of crucibles, tubes, and apparatus exposed to corrosion at high temperatures in the chemical and metallurgical industries. The authors present extensive quantitative data on its resistance to attack by a wide variety of reagents at temperatures up to 1825° C. These reagents include: (1) The acids, alkalis, etc. encountered when sintered alumina is used to make analytical crucibles; and (2) molten metals, carbon, silicon, various oxides, glasses, and slags, to which the material might be exposed in industrial plant. The authors predict that sintered pure alumina will play the same part in chemical and metallurgical engineering at temperatures from 1200 to 1800° C. as is now played by glass and porcelain at temperatures up to 1200° C.—J. C. H.

Fundamental Investigation of Steel Plant Refractories Problems. A. Muan and E. F. Osborn. (*Indust. Heating*, 1952, **19**, Feb., 317–320; May, 905–912, 944–948; June, 1098–1106; July, 1293–1298; Aug., 1492–1498; Sept., 1696–1704). The authors report on an investigation into phase equilibria in a portion of the system CaO–FeO–Al_2O_3–SiO_2. The systems $2CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO, $CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO, and $2CaO.SiO_2$–$CaO.SiO_2$–$2CaO.Al_2O_3.SiO_2$–FeO have been investigated and equilibrium diagrams and phase equilibria in these systems are discussed in detail. Crystalline phases were identified by examination under the microscope, by X-ray techniques, and by studying polished sections. The last part reviews in detail the X-ray data for the crystalline phases.—B. G. B.

Carbon Refractories for Blast Furnaces. J. J. Hazel. (*Yearbook Amer. Iron Steel Inst.*, 1952, 309–351). A number of breakouts in carbon-hearth blast-furnaces occurring in 1948 led to an extensive survey, the results of which are summarized. In almost all cases considerable erosion took place in the vicinity of the slag notch, the side wall blocks remaining in excellent condition. This erosion is felt to be due to steam oxidation from the tap-hole clay, and test data are presented in support of this. Results of research into the the properties of carbon refractories are given, and the design of carbon hearths is then discussed. The author concludes that carbon is a suitable material for blast-furnaces provided that due importance is attached to its oxidation rate and thermal conductivity, as proper consideration of the latter can reduce oxidation to a negligible amount.—G. F.

Preparation and Ramming-in of Carbonaceous Blast-Furnace Linings. J. Dobrý. (*Hutnické Listy*, 1952, **7**, 12, 619–626). [In Czech]. Problems in the manufacture of carbonaceous blast-furnace linings are examined, and experimental data are presented. Methods of manufacture, advantages and disadvantages, control of production and the most important physical properties of the lining material are discussed. Methods and tools employed for ramming-in are described, and the effects of the procedure on the porosity, tensile strength, impact strength, and other properties of the finished lining are explained. Experimental equipment is described and results obtained in a study of the effects of heat at increasing depth of carbon refractories are reported.—P. F.

Modifying the Life of Basic Converter Linings. W. Eilender and J. Schoop. (*Stahl u. Eisen*, 1952, **72**, Nov. 20, 1513–1520). In present-day practice a mixture with the best possible ramming density is required for converter bottoms. This property is to a large extent controlled by the sieve analysis of the particles, the time of grinding, the viscosity of the tar, and the mixing temperature. Investigations of the influence of ramming energy on the porosity indicate that the grist of the dolomite in a tar–dolomite mixture has no effect when the amount of ramming exceeds certain high values. Modifying the wear resistance of a tar–dolomite bottom depends not only on grain size and type of tar, but also on consolidation.—J. P.

Periclase Refractories in Rotary Kilns. L. W. Austin. (*Min. Eng.*, 1952, **4**, Oct., 980–983). The effects of chemical attack, mechanical stress, thermal shock, and abrasion on refractories in rotary kilns are discussed.—K. E. J.

Determination, by Means of Nomograms, of the Thickness of Lagging for Steam Pipes. J. Breuil. (*Chim. et Ind.*, 1952, **68**, Oct., 530–533).—T. E. D.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Results Obtained at Denain on the Cowper Stoves of Number 3 Blast Furnace. D. Petit. (*Rév. Mét.*, 1952, **49**, Sept., 623–632). Two old stoves were rebuilt with variable-turbulence brickwork. Fundamental tests in 1947 showed that this system enables more heat to be stored without increasing the exit gas temperature. Industrial trials for one month showed that the stove top temperature never exceeded 1280° C., and the efficiency of the stoves was 91·34%. Higher blast temperatures and/or longer 'on-blast' periods were made possible.

Blowers and Sources of Blast-Furnace Blast. F. Kulhánek. (*Hutnické Listy*, 1952, **7**, 12, 631–633). [In Czech]. The use and efficiency of blowers of various types, and sources of blast leakage, their detection, measurement and control, are discussed.—P. F.

Blower and Fan Costs. R. E. Denzler. (*Chem. Eng.*, 1952, **59**, Oct., 130–134). Operating cost/capacity graphs for three basic types of air moving equipment are given and explained. They include: Axial flow propeller fans and blowers; radial flow centrifugal fans and blowers; and positive rotary blowers, gas pumps, and compressors.—T. E. D.

Two Methods—Drying and Moistening of Air Blast. J. Šárek. (*Hutnické Listy*, 1952, **7**, 12, 627–628). [In Czech]. It is shown that, contrary to widely held views, a high moisture content in blast-furnace blast need not increase specific coke

consumption, as the hydrogen liberated in the endothermic decomposition of the steam contributes to the reduction of the iron ore. Calculations in support of this view are given, and successful long-term experiments in Russian ironworks with a blast preheated to 790° C., containing 2·44 vol.-% of moisture, in which reductions of the specific coke consumption by 1·35 to 4·37% were attained, are mentioned.—P. F.

Blast-Furnace Charging by Means of Conveyor Belts. S. Černoch. (*Hutnické Listy*, 1952, **7**, 12, 628–631). [In Czech]. A recently developed method of using rubber conveyor belts for transporting and charging coke and ore into blast-furnaces is described. Illustrations of the installations at a Czechoslovak steelworks are shown. Good results are obtained.—P. F.

Towards Low Coke Consumption. J. Šárek. (*Hutnické Listy*, 1952, **7**, 12, 633–635). [In Czech]. Methods leading to lower coke consumption in blast-furnace practice are discussed. Superheated blast, uniformity of charge, agglomeration of ores, continuous control of blast-furnace performance, ore concentration, the use of oxygen-enriched blast, and other methods, are examined.—P. F.

Works' Trials to Determine the Coke Consumption for Remelting Pig Iron and Scrap in the Blast-Furnace. C. Wens. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1391–1397). The data in the literature about coke consumption in remelting pig iron differ markedly from those found in practice. Works' trials were therefore carried out to determine the coke consumption accurately. The trials were extended to cover scrap and granulated pig iron. The results were checked in several ways and converted to a common and comparable basis of operating conditions. For the burdening conditions in the Ruhr blast-furnaces, the coke consumption for lumpy pig iron was 280–300 kg. per ton, for scrap it was about 420 kg. per ton, and for granulated pig it was 120–170 kg. per ton. The difference in consumption for lumpy and granulated iron is caused by the lumps reaching the bosh with a lower temperature than the normal burden, and therefore requiring more coke to melt them.—J. P.

Desulphurization of Pig Iron Outside the Blast-Furnace. (*Biuletyn Informacyjny Instytutu Metalurgii*, 1952, No. 10, pp. 37–39, *Hutnik*, 1952, No. 10). [In Polish]. Desulphurization of pig iron with sodium chloride and with burned lime is described. Sodium chloride was added into the runner in amounts of about 0·2% of the iron. The results varied but significant desulphurization was obtained when the initial sulphur was above 0·05%, but obnoxious and copious fumes made the process impossible without special ventilation. A small rotating drum (5½ in. in dia.) was placed in a side runner in such a way that the iron flowed straight into the drum where it mixed with lime and ran out further down the runner. A device to increase the mixing time in the drum was incorporated. In further experiments, about 100 kg. of iron were passed through the drum in about 2 min. and the results were satisfactory, even when the initial sulphur in the iron was only 0·03%. The amount of lime was of the order of 10% of the iron. Full experimental data are given.

Large Instrument Panels: Comprehensive Installations for Shotton Works and B.E.A. (*Iron Steel*, 1952, **25**, Nov., 493). Brief descriptions are given of the large instrument panels which are being made by George Kent Ltd. for the blast-furnace plant of John Summers and Sons, Ltd.—G. F.

Sulphur: Importance in the Iron and Steel Industry. E. C. Evans. (*Iron Steel*, 1952, **25**, Nov., 495–500). The author deals with some of the many important aspects of sulphur in the iron and steel industry. He discusses the influence of sulphur in blast-furnace and steelmaking practice, desulphurization outside the blast-furnace, removal of sulphur from coke-oven gas, and the recovery of sulphuric acid from waste pickle liquor.—G. F.

Iron Production in a Rotary Furnace. A. Lincke. (*Met. u. Giesserei Techn.*, 1952, **2**, Feb., 45–47). This process has advantages over the blast-furnace where very pure pig iron is wanted, coking coal is not available, or ores are not suitable, at least without previous preparation. It produces iron with low silicon and less than 0·01% sulphur. The rotary furnace, about 41 ft. long and 14 ft. in dia. is fired by a pulverized coal burner at one end and the hot exhaust gases are drawn in turn through a limestone burner, ore preheater, recuperator for preheating air, and coke drier. It is mounted on a turntable so that it can be turned end for end every 2 hr. or to an intermediate position for charging. It can be tilted for tapping. Poor-quality fuels can be used for reduction.—H. R. M.

The Treatment of Ilmenite from Lake Allard at the Electric Smelting Works at Sorel (Canada). (*J. Four Elect.*, 1952, **61**, Sept.–Oct., 129–133). By close control of the mining and handling procedure a raw material having a fairly constant composition (88–90% mixed oxides of titanium and iron) is brought by boat to the smelting works at Sorel. The process consists of separating out the iron by reducing the material in an electric furnace and producing a slag rich in titanium dioxide. Each electric smelting furnace is rectangular in shape and has six graphite electrodes in line, two for each phase of a three-phase current at 224–390 V. The fusion temperature is about 1650° C. The charge treated by each furnace per day is 300 tons of mineral with 43 tons of carbon, and 132 tons of slag and 96 tons of refined iron are produced. The iron produced is refined in separate arc furnaces where the sulphur content is reduced from 0·60 to 0·04%.—B. G. B.

Obtaining Pig Iron from Electric Reduction Furnaces. H. Walde. (*Inst. Hierro Acero*, 1952, **5**, Oct., 969–976). [In Spanish]. The author describes the principles of the low shaft furnace and compares it with the electric blast furnace. The work of Durrer is reviewed. Photographs of the low shaft furnace are presented.—R. S.

The Spatial Representation of Physico-Chemical Processes, Particularly Melting and Reduction Reactions, by the Anaglyph Method. M. Linhard. (*Metall u. Erz*, 1940, **37**, June, No. 12, 228–231). An anaglyph, when examined at the correct distance and angle through suitably tinted spectacles, gives a stereoscopic effect. The article gives three applications of this method: (1) A drawing of the ternary system Pl–Bi–Zn; (2) a body-centred cubic crystal lattice; and (3) an equilibrium diagram of the reduction of iron oxides by carbon monoxide. An example of the method is given.—L. H.

DIRECT PROCESSES

Hydrogen Reduction of Ores. V. Aravamuthan. (*Metal Market Review*, 1952, **5**, Aug. 15, 34–40). The direct reduction of iron ores by hydrogen is first discussed and the author considers that this method is far superior to the blast-furnace method. An indirect method is also described in which the ore is first reduced to the magnetite stage, magnetically separated from the gangue, and then reduced to the ferrous oxide. The ferrous oxide is later reacted with ammonium chloride to yield ferrous chloride which is then reduced by hydrogen. The author considers that this process would be commercially successful where large deposits of alkaline earth sulphate materials, iron oxide or sulphide, and low-grade coal occur within a few miles of one another.—B. G. B.

PRODUCTION OF STEEL

Presidential Address: From the Ore to the Ingot. J. Mitchell. (*J. Iron Steel Inst.*, 1953, **174**, May, 1–8). [This issue].

Work Process Analysis as a Basis for Rationalization in Steelworks. M. Förster. (*Stahl u. Eisen*, 1952, **72**, Nov. 20, 1524–1531). The value of the analysis of working procedures and operations in steelworks as an aid to increased productivity and cost reduction is illustrated by several examples. The analysis studies the connection and sequence of individual operations, both consecutive and simultaneous. From this the best lay-out and sequence were determined. Work analysis is thus seen to be a suitable basis for operational planning. The indispensable preliminary studies to be carried out before undertaking work process analysis are discussed.

The Refining of Basic-Bessemer Pig Iron with Carbon-Dioxide/Oxygen Mixtures. K. Meyer, H. Knüppel, and H. J. Därmann. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1409–1416). Works' trials with the carbon-dioxide–oxygen process have been carried out in 25- and 30-ton converters. Control was difficult because the flame is very luminous throughout the whole blow. The refining process and waste gas analysis were followed by taking samples from the blowing converter. Nitrogen contents of the trial melts ranged from 0·002–0·010%. No flushing out of the nitrogen during the phosphorus period was detected although the CO–O_2 mixtures repressed the nitriding tendency. The final nitrogen content depended on the nitrogen at change-over to CO_2–O_2 blowing. The oxygen content was higher than with open-hearth steels. The metallurgical advantage of the process is the reliability of being able to finish with nitrogen contents below 0·004% and so obtain a good rimming, deep-drawing steel. There are insufficient metallurgical or economic grounds for introducing the CO_2–O_2 process.—J. P.

Properties of Mild Steels Blown with Oxygen-Steam Mixtures. A. Krüger. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1426–1433). A number of basic-Bessemer heats, blown with steam–oxygen mixtures, were compared in chemical composition and mechanical properties with those from melts blown with oxygen-enriched air and with normal basic-Bessemer and open-hearth steels. The nitrogen contents of the new steels were up to 47% lower than those of open-hearth steels, and the phosphorus content was between those of open-hearth and basic-Bessemer steels. Ductility after ageing could not be correlated with phosphorus, nitrogen, and oxygen contents; 36% of the melts were the equal of those from the open-hearth furnace. As far as the effect of temperature on ductility was concerned, the low phosphorus melts behaved like open-hearth steel and the high phosphorus melts like basic-Bessemer steels. The yield stress, tensile strength, elongation, and reduction of area were as good as those of open-hearth steels or better. No detrimental effect attributable to hydrogen could be detected, and the material hardened under cold work to a lesser extent than open-hearth steels. The favourable forging properties of this new steel have been proved.

Basis for Calculating the Charge for Making Ordinary Steels in Basic Open-Hearth Furnaces. III. P. Krynicki. (*Bol. Assoc. Brasil. Met.*, 1952, **8**, Apr., 185–202). [In Portuguese]. The principles dealt with in Part II (*see J. Iron Steel Inst.*, 1952, **172**, Dec., 433) are elaborated and applied to the cases of carburizing hot and cold metal charges in the open-hearth furnace, and making additions of ore and scrap. An example of the calculation of the manganese ore addition is also given.—R. A. B.

The Water Cooling of Open-Hearth Furnaces. A. M. Frankau. (*J. Iron Steel Inst.*, 1953, **174**, May, 46–52). [This issue].

Charging Open Hearth Furnaces. C. Croxford. (*Brit. Steelmaker*, 1952, **18**, Dec., 692–694, 709). The author has made a special study of scrap processing and furnace charging procedures in Northern France and Germany, and makes practical suggestions for improving the charging facilities in British open-hearth shops.—G. F.

Developing the Use of Coke-Oven Gas in the Open Hearth. J. H. Kelley. (*Yearbook Amer. Iron Steel Inst.*, 1952, 371–385). The author describes the development of a practical method for burning up to 70% of coke-oven gas with oil fuel in open-hearth furnaces, a combination burner being used in which the gas is introduced separately above the oil. Experimental and production data are presented illustrating the resulting increase in production, an important factor being the higher checker and air preheat temperatures permissible owing to the smaller alkali checker deposits with this method of firing.—G. F.

Sampling Liquid Steel Baths for Oxygen Content. K. G. Speith and H. vom Ende. (*Stahl u. Eisen*, 1952, **72**, Nov. 20, 1521–1523). A small wood-covered 'bomb' is described. It enables samples for oxygen determination to be taken in a simple manner. Before vacuum-fusion analysis, the lower part of the sample is forged down to a 10-mm. square section and pieces 6–7 mm. in dia. × 15–17 mm. long are machined therefrom. Metallographic and chemical examinations indicate a uniform distribution of oxygen.—J. P.

Casting Large Ingots. W. H. Stratford. (*E.S.C. News*, 1952, **6**, 2, Autumn, 2–10). The author gives a complete description of the casting of very large ingots, up to 270 tons, from the time the steel leaves the furnaces to the delivery at the forge. Apart from the actual casting, he considers mould design, ladles, pit-side planning, and procedure.—J. C. B.

Contribution to the Problem of Active Mixers. A. Děkanovský. (*Hutnické Listy*, 1952, **7**, 9, 450–456). [In Czech]. The problem of the efficiency of active mixers used for the pre-treatment and mixing of pig iron in open-hearth steelmaking is examined in detail. Results of experiments using a 400-ton tilting mixer are described, and the metallurgy of active mixers and their use abroad are discussed. Experiments in which air and water were blown into the mixer or into the liquid metal stream entering the mixer were carried out, but were not satisfactory in refining the metal. The increase in the efficiency of open-hearth furnaces fed from active mixers was established at about 1% over a long period, but an economic analysis of the complete system showed the provision of active mixers resulted in no appreciable advantages.—P. F.

Open Hearth Zebra Roof Experience Analyzed. T. H. Harley. (*J. Met.*, 1952, **4**, Nov., 1146). The results of an extensive survey to determine the extent, type, and results of the use of zebra roofs in U.S.A. and Canada are summarized. For every seven furnaces, zebra roofs were successful on two, unsuccessful on four, and questionable on one furnace. No definite trends showing where the design will perform satisfactorily are indicated.—G. F.

Evolution of the Electric Furnace in American Steelworks. (*J. Four Elect.*, 1952, **61**, May–June, 87–89; July–Aug., 109–110). A comparison is first made between European and American electric furnace practice. The tendency to use large arc furnaces of 60–100 tons capacity in the U.S.A. is not a substitute for the open-hearth furnace working in conjunction with blast-furnaces and coke ovens. Its most economic use is where pig iron is scarce (as on the Pacific coast) or where metal turnings are abundant (as in the Detroit and Cincinnati districts).—B. G. B.

Söderberg Electrodes for Electric Steel Furnaces. T. Wahlberg and N. Winblad. (*Jernkontorets Ann.*, 1952, **136**, 9, 375–411). [In Swedish]. Advantages and disadvantages of five types of Söderberg electrode shells are discussed, four having radial ribs and one with central plate reinforcement. Tests with various 500-mm. and 720-mm. electrodes to establish consumption rate as a function of shell design proved the radial rib construction to be inferior. A study of their operating characteristics showed that the coking temperature of present-day electrode pastes was between 400 and 450° C. When Wohlfahrt packing is used the coking front is normally in the lower edge of the holder. Shell thickness had no apparent influence on the form of the coking front and variations in electrode dimensions did not affect coking. Some details are given of electrode jointing, coking after breakage, and electrode protection in the furnace.—G. G. K.

The Electric Melting Furnace in the Steel Industry. G. Simon. (*Met. u. Giessereitechn.*, 1952, **2**, Mar., 66–69). The three types of electric melting furnaces—with resistance heating, arc heating, and induction heating—are reviewed, and indications are given of the probable lines of future development.—H. R. M.

The Use of Oxygen in Electric Furnaces. L. Antonio de Araujo. (*Bol. da Assoc. Brasil. Metais*, 1952, **8**, Apr., 125–132). [In Portuguese]. The history of the use of oxygen in steelmaking is briefly reviewed. The chemical reactions during the blow, and the equipment and methods of working are considered. The advantages of injecting oxygen are pointed out and difficulties to be expected when introducing the technique in Brazil are discussed.—R. S.

Formulae and Tables for the Calculation of the Impedance of Bus Bars in Electric Furnaces. F. V. Andrae. (*J. Four Elect.*, 1951, **60**, Mar.–Apr., 40–42; May–June, 73–75; July–Aug., 99–102; Sept.–Oct., 126–129; Nov.–Dec., 154–157; 1952, **61**, Jan.–Feb., 24–25; Mar.–Apr., 57–60).

Semi-Microchemical Method for the Determination of Slag Basicity. B. A. Generozov. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 666–668). [In Russian]. The method of determining slag basicity described depends on the water-extraction of the lime under such conditions that the proportion of the total lime extracted is high and proportional to the lime-content. This was achieved by energetically shaking a 0·1-g. freshly ground sample (through 200 mesh) with 250 ml. water at 18–20° C. for 8–10 min. Distilled water, free from CO_2, was used. The aqueous extract was rapidly filtered and an aliquot portion was titrated with 0·01N HCl in the presence of a mixed indicator. The basicity was then found from calibration tables.—S. K.

Heats of Formation of Manganous Metasilicate (Rhodonite) and Ferrous Orthosilicate (Fayalite). E. G. King. (*J. Amer. Chem. Soc.*, 1952, **74**, Sept. 5, 4446–4448).

The Distribution of Phosphorus between Molten Iron and Lime-Saturated Slags at Temperatures of 1530 to 1700° C. W. A. Fischer and H. vom Ende. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1398–1408). The distribution of phosphorus between molten iron and lime-saturated iron oxide slags has been investigated in a lime crucible at temperatures between 1530 and 1700° C. The slags contained only traces of silica, magnesia, and alumina. They contained up to 38% P_2O_5, between 32 and 58% CaO, and between 2 and 50% total iron. With slags with P_2O_5 contents normal for basic-Bessemer practice (20–25%), the equilibrium phosphorus content of the iron was found to be about 0·01% at 1530–1570° C., about 0·02%

at 1580–1620° C., and about 0·03% at 1630–1700° C. It is noteworthy that the activity of ferrous oxide in the slags scarcely changed in the range 20–50% total iron, but changed rapidly as the total iron increased to 20%. This constancy may be due to a tendency of the slags to separate into two phases, though no evidence was found of immiscibility. The oxygen content of the iron lay between 0·025 and 0·12%, depending on temperature and phosphorus content. The free-energy change in the dephosphorization reaction was calculated on the assumption that the lime and calcium phosphate activities in the slags were unity. The structure of the quenched slags showed primary precipitation of tricalcium phosphate. The residual solid appeared to be a ternary eutectic of finely divided iron, dicalcium ferrite, and lime-bearing wüstite.—J. P.

Advances in Thermodynamics. J. R. Partington. (*Nature*, 1952, **170**, Nov. 1, 730–732). The development of thermodynamics since the work of Camot in 1824 is discussed. Recent advances in the applications of thermodynamics in chemistry are considered in connection with the following four books: *Eléments de thermodynamique chimique*, by G. Allard; *Chemical Thermodynamics*, by F. D. Rossini; *Principles of Chemical Thermodynamics*, by M. A. Paul; and *The Thermodynamics of the Steady State*, by K. G. Denbigh.—A. G.

Oxygen Flame Deseaming of Ingots. E. Ritter and H. Didier. (*Schweissen u. Schneiden*, 1952, **4**, Oct., 364–370; Nov., 394–396). The gas flame deseaming process is described and metallurgical properties and structure of the surface of the cleaned ingots are discussed. The difference between flame-cleaning and oxygen-cutting is explained, and some American flame cleaning machines are illustrated.—U. E.

PRODUCTION OF FERRO-ALLOYS

Recent Experiments in the Recovery of Manganese. S. Marshall. (*Yearbook Amer. Iron Steel Inst.*, 1952, 289–306). The author describes three methods which experimental work has shown to be technically feasible for recovering manganese from open-hearth slags. The methods are: (1) A pyrometallurgical process which produces a high-manganese slag suitable for smelting in a blast-furnace to produce ferromanganese; (2) a process in which the slag, after clinkering with lime, is leached with ammonium carbonate; and (3) treatment of the slag with solid or gaseous chlorides, causing volatilization of iron and manganese chlorides, and leaving behind the gangue. The progress made in each process is outlined.—G. F.

FOUNDRY PRACTICE

The Basic Cupola. M. Ferry. (*Fonderie*, 1952, Aug., 3060–3064). The author summarizes the present position of the development of basic cupolas, preparatory to a research project by the Centre technique des Industries de la Fonderie. He concludes that desulphurization and dephosphorization cannot be carried out simultaneously and be compatible with maximum yield, since the former requires a reducing basic slag and the latter an oxidizing basic slag. Dephosphorization with good yields is possible only when the silicon is very low.—R. S.

A Study of Some Metallurgical Factors Influencing Chill and Mottle Formation in Cast Iron. W. J. Williams. (*Brit. Cast Iron Res. Assoc.*: *J. Res. Development*, 1952, **4**, Oct., 403–423). An investigation into the effects of superheating, inoculation, melting stock, and oxygen, on the chilling properties of low silicon cast irons is reported. An attempt is made to correlate some of the results obtained with existing information and theories on the effects of superheating and inoculation on chill formation.—B. G. B.

Carbon Pick-Up. H. T. Angus. (*Brit. Cast Iron Res. Assoc.*: *J. Res. Development*, 1952, **4**, June, 360–364). The author surveys and assesses the relative value of methods of improving carbon pick-up. The chief factors promoting carbon pick-up in the cupola are adequate melting temperature, a deep combustion zone, good quality low-ash coke, and intimate contact between molten metal and incandescent coke. Metal composition is also an important factor.—B. G. B.

Purification of Cupola Fumes. (*Fonderie*, 1952, July, 3027–3031). The nature of cupola fumes and the operation of static and dynamic purifiers are described.—R. S.

Acicular or Bainitic Cast Irons. (*Fonderie*, 1952, Aug., 3071–3072). Compositions of acicular cast irons are discussed, with a brief note on the requisite heat-treatment and properties obtainable.—R. S.

A Note on the Graphitization of Martensite. J. W. Grant. (*Brit. Cast Iron Res. Assoc.*: *J. Res. Development*, 1952, **4**, Aug., 366–368). An investigation into the formation of graphite nodules from martensite, following heat-treatment, in pre-quenched specimens of nodular and flake graphite irons is reported. The martensite of the quenched nodular iron decomposed into numerous small nodules, their size increasing as the quenching temperature increased. With high quenching temperatures the nodules were longer and tended to join up in rows. Irregularly distributed aggregate-type nodules were deposited from the quenched flake-graphite irons.—B. G. B.

Spheroidal Graphite Cast Iron. J. McNeil. (*Metal Market Review*, 1952, **5**, Aug. 15, 41–49). The manufacture, properties, and applications of spheroidal graphite cast iron, produced by the magnesium process, are discussed.—B. G. B.

Malleable Cast Irons. P. Ryš. (*Hutnické Listy*, 1952, **7**, 10, 519–522; **11**, 585–588). [In Czech]. A survey of present-day methods of producing and heat-treating malleable cast irons in the larger industrial countries is given, and the probable course of further developments is outlined. In the second part, types and properties of malleable cast irons produced in other countries are surveyed and discussed.—P. F.

The Influence of the Sulphur/Manganese Ratio on the Occurrence of Mottle in Whiteheart Malleable Iron. S. W. Palmer. (*Brit. Cast Iron Res. Assoc.*: *J. Res. Development*, 1952, **4**, Oct., 394–402). Tests were carried out on both crucible and cupola melted specimens of malleable iron. Reducing the value of the sulphur/manganese ratio increased the tendency to mottle. Mottle, however, was found to be offset by one of the following methods according to size: (1) A reduction of 0·1% in the silicon; (2) reductions of 0·1% in the total carbon and 0·05% in the silicon content; and (3) a reduction of 0·2% in the total carbon content. It is believed that the total carbon content of whiteheart iron could, in many cases, be safely reduced by 0·02% and this, in conjunction with a reduction in the sulphur/manganese ratio from 1·0 to 0·65, should give an all-round improvement. No evidence was obtained, within the composition range studied, that any reduction in mottle was effected by increasing the manganese from a small excess to a large excess content. Evidence of a secondary type of mottle is put forward; in extreme cases this can give rise to inverse chill.—B. G. B.

Cast Iron with Spheroidal Graphite: Present Views on Its Production and Mode of Crystallization. Properties and Applications. M. Ballay. (*Usine Nouvelle*, 1952, Apr. 24, 23–25). Theories on the formation of the spheroids are briefly discussed. The mechanical properties of spheroidal cast iron are compared with those of steel and ordinary cast iron, and the production of various types of spheroidal cast iron is considered.—T. E. D.

Chemical and Physical Changes in Magnesium-Treated Irons. M. Okamoto and R. Yoda. (*Foundry*, 1952, **80**, Oct., 126–127). Chemical and physical changes in magnesium-treated cast irons during the time before pouring have been investigated. It is concluded that a suitable molten iron which will easily spheroidize on adding magnesium must be one on which a magnesium-carbide slag with strong reducing action will readily form.—E. T. L.

The Production and Applications of Spheroidal Graphite Irons in the U.S.A. C. Galletto. (*Fonderia Ital.*, 1952, **1**, Sept., 161–168). The author reviews American production techniques and applications for spheroidal graphite irons. Practices relating to different works are described and many details are given of the development of new applications for this material.—M. D. J. B.

Short Cycle Annealing of Whiteheart Malleable Castings. P. F. Hancock. (*Proc. First World Metallurgical Congress*, Sept., 1951, 376–390 : Amer. Soc. Met., 1952). Recent British developments in the heat-treatment of whiteheart malleable iron castings using controlled atmosphere furnaces are described. The modern gaseous annealing furnace maintains the required atmosphere by a self-regulating system.

Comparison Between Two Malleablizing Furnaces. H. Tegelhütter. (*Giesserei*, 1952, **39**, Sept. 18, 519–521). A chamber and a continuous furnace are compared from the point of view of manning, output, heat balance, and microstructure of product.—J. G. W.

Physical-Chemical Principles of Malleablizing in a Gas Stream. K. Roesch. (*Giesserei*, 1952, **39**, Sept. 18, 487–491).

Recent fundamental investigations of reactions when malleablizing in gas furnaces are reviewed. The advantages of this process are discussed, and it is concluded that development of furnace design and knowledge of the principles underlying the process are sufficiently advanced for practical purposes.

Enlarged Malleable Iron Foundry is Model of Good Housekeeping. F. G. Steinebach. (*Foundry*, 1952, **80**, Sept., 100–105, 278–284). The layout and equipment of the modernized plant of the Albion Malleable Iron Co., Albion, Mich., is described in detail. The plant produces about 3600 tons of castings per month for which the metal is supplied from two water-jacketed cupolas and two air furnaces, one cupola operating with hot blast.—R. A. R.

Electric Heating of Feeders for Heavy Steel Castings. W. Rietzscher. (*Giesserei*, 1952, **39**, Oct. 16, 553–558). Based on experiments in the Krupp steel foundry, Essen, solidification rates were determined, and the effect of segregation examined; from these, data for electric heating of gates by insertion of electrodes were obtained. The procedure is applicable for wall thicknesses exceeding 4 in.—J. G. W.

New Methods in the Production of Steel Castings in the U.S.S.R. R. Kamenský. (*Hutnik* (Prague), 1952, **2**, 7–8, 159–161). [In Czech]. Recent advances in steel-casting processes, as described in a lecture by P. N. Bidulij in Prague, are reported and discussed.—P. F.

Methods for the Economical Production of Steel Castings. T. Witkowski. (*Przeglad Odlewnictwa*, 1952, No. 5, 147–152). [In Polish]. Attention is drawn to the losses of metal in feeding heads, and the time and materials spent on their removal. Methods of reducing these losses are discussed.—V. G.

Casting Steel in Dry Sand Molds. S. R. Robinson. (*Foundry*, 1952, **80**, Apr., 170–171). The author reviews the types of sand mould for steel castings, and outlines the procedures for casting an H beam and a double-branch pipe.—E. T. L.

Production of Manganese-Steel Castings. F. Cousans and W. C. Meredith. (*Inst. British Foundrymen Preprint* 1032, June, 1952 : *Foundry Trade J.*, 1952, **93**, Sept. 11, 287–293). Following a brief history of manganese steel, the authors describe present-day foundry methods for this material, Moulding materials and washes, feeding heads, pouring, knocking-out, and quenching are dealt with, and the account ends with descriptions of mould layouts.—E. T. L.

The Behaviour of Various Cooling Agents during the Pouring of Steel Castings. E. Lanzendörfer and K. Hilterhaus. (*Giesserei*, 1952, **39**, Sept. 18, 483–486). Experiments are described in which Bessemer steel specimens were cast with inserted cooling pins made of ordinary and aluminium-rich Bessemer steel, and of silicon-killed and rimming open-hearth steel. Killed steels are to be preferred ; on the other hand, rimming steel core supports are safer.—J. G. W.

Induction Furnace Melting of Corrosion Resistant Alloys. B. Spindler. (*Foundry*, 1952, **80**, Aug., 110–113). The equipment and methods employed by Alloy Steel Products Co., Linden, N.J., for casting chromium-nickel steel valves and pipe fittings are described and illustrated. Two 600-lb. Ajax-Northrup basic-lined induction furnaces supplied from a 175-kW. 960-cycle motor-generator set are used.—R. A. R.

Small Foundry, Small Castings. (*Amer. Foundryman*, 1952, **22**, Sept., 37–39). This is a description of Goltra Foundries Ltd. plant, said to be the ' smallest, least orthodox, and most highly mechanized steel foundry ' in America. It specializes in small, accurately made castings.—E. T. L.

How to Develop Cast Products. R. J. Franck. (Steel Founders' Soc. of America : *Foundry*, 1952, **80**, Oct., 120–123, 205). The author outlines a procedure for developing the efficient production of steel castings, dealing with testing of experimental designs, costs, sample castings, and stress analysis of these with a brittle lacquer technique.—E. T. L.

Bentonite as Moulding Sand Binder. O. Eckart. (*Giesserei*, 1952, **39**, Oct. 2, 529–533). The binding capacity of bentonite is explained in fundamental terms by reference to its molecular structure and properties. Its use in moulding sand is discussed in the light of test data on the compressive strength of green sand, gas permeability, dry strength. sedimentation volume, and determination of exchangeable cations. Methods of making these tests are critically reviewed.—J. G. W.

Used Moulding Sand Reclaimed by Air Scrubbing. H. H. Fairfield. J, McConachie, and H. F. Graham. (*Canad. Metals*, 1952, **15**, June, 36–40). The low baked-compression strength of used sand cores is due to the impurities being mostly in the form of fines. A cleaning plant is described which removes the fines by a stream of air blown countercurrent to the flow of the sand. For moulding sands, the used sand must be passed twice through the reclaiming chamber. In order to produce a suitable core sand, however, the used sand had to receive additional treatment.—J. C. B.

The Re-Use of Old Sand. H. Reininger. (*Giesserei*, 1952, **39**, Oct. 16, 558–564). Regeneration of used moulding sand in the light of recent scientific research is discussed. Distribution of grain size, thorough removal of dust, and use of a clay of the bentonite type, are considered as means of restoring the moulding properties of the sand.—J. G. W.

Sand Reclamation at the Eddystone Plant. K. S. Howard and C. B. Jenni. (*Foundry*, 1952, **80**, Sept., 92–95, 274, 276). The sand equipment at the foundry of General Steel Castings Corp., Eddystone, Pa., is described.—R. A. R.

Sand Reclamation by Wet Methods. R. Webster. (*Foundry*, 1952, **80**, Oct., 238, 240). The cleanliness of reclaimed sand can be tested by the tensile strength of an oil-bonded baked specimen. A pilot plant capable of dealing with 1 to 3 tons/hr. is described very briefly.—E. T. L.

Apparatus for Determining the Gas-Permeability of Mould-Mixtures from the Water-Permeability. V. I. Fundator. (*Zavodskaya Laboratoriya*, 1950, No. 5, 635–636). [In Russian]. The disadvantages of the A.F.A. method for the direct determination of the gas-permeability of mould-mixtures are pointed out, and a simple indirect method, based on measurement of water-permeability is described. The new method was used on sand-clay mixtures, the following conclusions being drawn from the results : (1) The content in the mixture of highly dispersed and colloidal materials, such as bentonites with SiO_2/Al_2O_3 ratios of 5·8 to 7, should not exceed 3–4% ; (2) mould mixtures of clays with SiO_2/Al_2O_3 ratios of 28–34 can be recommended for facing ; and (3) the water-permeabilities of the more common mould materials lie within the range of 2–15%.—S. K.

Apparatus for Determining the Gas-Producing Properties of Mould Materials. A. A. Nizovtsev. (*Zavodskaya Laboratoriya*, 1950, No. 5, 637). [In Russian]. In the method of determining the gas-evolving properties of mould and core mixtures, the volume of gas produced in 30 sec. on heating a 1-g. sample to 1100° C. is measured in a gas burette. The accuracy claimed is 0·5–1 ml.—S. K.

A Study of Five Moulding Sands. S. Gonzalez Larrea. (*Inst. Hierro Acero*, 1952, **5**, July, 741–767). [In Spanish]. Five moulding sands used in the Bilbao region are studied.

The Disintegration of Lumps of Baked Sand in the Foundry. (*Fonderie*, 1952, Apr., 2898–2902). The paper describes machines for breaking up lumps of moulding sand removed from castings.—R. S.

Selection, Testing and Use of Bonding Clays in Synthetic Molding Sand. W. W. Kerlin. (*Foundry*, 1952, **80**, Aug., 86–91, 223–226). The author illustrates by examples that it is not sufficient to specify bonding clays in terms of chemical analyses or fusion point. Plasticity and water content are more relevant to practical usefulness. The physical structure of clays is discussed with reference to the montmorillonite, and the kaolinite—illite groups, and to bentonite. Strength and permeability are correlated with mixing time.—E. T. L.

Refractory Permanent Molds. J. B. McIntyre. (*Foundry*, 1952, **80**, Aug., 102, 103, 228, 232). This general discussion of permanent moulds deals with the use of grey cast iron, sintered iron powder, and aluminium alloys for moulds. Other materials mentioned include sillimanite, and electrode-graphite treated with ethyl silicate.—E. T. L.

What Causes Molding Green Strength? C. A. Sanders. (*Foundry*, 1952, **80**, Oct., 108–109, 283–286). The author discusses the relation between the plasticity of a clay to its green strength. Various theories accounting for this plasticity are briefly considered.—E. T. L.

Graphite and Its Uses in Metallurgy. A. Humann. (*Met. u. Giessereitechn.*, 1952, **2**, Jan., 29–31). The properties of graphite and the main sources of the different types are described. The main uses are for coating foundry moulds and cores, for making crucibles and electrodes, and as an addition to lubricants, and the suitability for these purposes of graphite from different sources is discussed.—H. R. M.

Graphite and Its Applications in the Foundry. (*J. Four Elect.*, 1951, **60**, Sept.–Oct., 124–123). This is a general review of the uses of graphite in foundry practice.—B. G. B.

Suggestions for Designing a Steel Foundry Fettling Shop. R. Chudzikiewicz. (*Przeglad Odlewnictwa*, 1952, **2**, 9, 283–289). [In Polish]. The fettling shop operations are outlined. The mechanization of cleaning castings and the choice of equipment are discussed. Examples of shop design are given.—V. G.

Roll Casting in Yugoslavia. E. Scharffenberg. (*Giesserei*, 1952, **39**, Nov. 13, 606–608). The development of a foundry for the production of cast rolls within the framework of the 1947 five-year plan in Yugoslavia is described.—J. G. W.

Use of Propane in the Foundry. M. Decrop. (*Fonderie*, 1952, July, 3023–3026). Propane can be used in the foundry for several kinds of portable heating apparatus. The author reviews its physical and chemical properties, and methods of stocking, transportation, and supply.—R. S.

Phenomena During the Heating of Moulds for Steel Castings. A. Roth. (*Giesserei*, 1952, **39**, Oct. 30, 585–587). Beneficial and deleterious effects of the transfer of heat through the mould walls during the solidification and cooling of castings are discussed. It is shown how the cooling rate can be modified by suitable design, and the use of hot tops.—J. G. W.

Fifty Years in a Foundry: Some Reminiscences of an English Foundryman. W. Gudgeon. (*Iron Steel*, 1952, **25**, May 17, 198–201, 235).

Rejects—Their Cause and Prevention. M. Söllner. (*Giesserei*, 1952, **39**, Oct. 30, 592–593). The causes and cures for common defects in castings are discussed.—R. A. R.

The Problem of Classifying Casting Defects. K. Gierdziejewski. (*Hutnické Listy*, 1952, **7**, 10, 506–514). [In Czech]. The development of methods of classifying casting defects is surveyed. The classification proposed by Plešinger is discussed, and its advantages and drawbacks considered.

Vacuum Impregnation of Castings. (*Tecn. e Industr.*, 1952, **30**, Aug., 810). [In Spanish]. This brief note mentions some of the newer materials used for the vacuum impregnation of castings to close up porous parts.—R. S.

Economic Trends and Costing. A. Reuterskiöld. (*Gjuteriet*, 1952, **42**, Oct., 155–156). [In Swedish]. Precise knowledge of cost distribution is essential for process rationalization which is the only way to reduce foundry costs. Should credit restrictions hinder capital investment, correct utilization of resources must be secured and this can be ensured only by cost-consciousness in managements.—G. G. K.

Uniform Instruction for Apprentices in the Foundry. H. Pieper. (*Giesserei*, 1952, **39**, Dec. 11, 649–657).

Prevention of Silicosis. A. G. Thomson. (*Australian Found. Trade J.*, 1952, **3**, Aug., 21, 22). Brief notes are given of investigations now proceeding in Great Britain in an attempt to establish standards of maximum dust concentrations which may safely be tolerated by foundry workers.—P. M. C.

HEATING FURNACES AND SOAKING PITS

Standardization in Industrial Furnace Construction. R. G. Zeppernick. (*Metall u. Erz*, 1941, **38**, Sept., No. 18, 404–406). The advantages of standardization of furnace materials and construction are indicated. The direction and scope of the work are outlined, and examples of existing German standardization are given.—L. H.

Heating Steel Bars for Continuous Hot Heading Operations. (*Indust. Heating*, 1952, **19**, Sept., 1614–1620). A continuous furnace for the rapid heating of the ends of bars for forging and heading is described. There is a refractory lined, slot-type chamber with closely spaced, high intensity ribbon burners firing from below. The feed mechanism is capable of handling bar stock from $\frac{5}{8}$ to $1\frac{3}{8}$ in. in dia. and 6 to $43\frac{1}{4}$ in. long.—B. G. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Army Tank Turrets Handled Automatically During Heat-Treatment. (*Indust. Heating*, 1952, **19**, Sept., 1624–1628). The use of electrically operated tongs to handle tank turrets, weighing from 7 to 12 tons each, enables the operations of heating for hardening, quenching, tempering and requenching to be carried out by remote control.—B. G. B.

A Modern Plant for the Heat-Treatment in an Electric Furnace of Motor-Car Spanners. (*J. Four. Elect.*, 1952, **61**, Jan.–Feb., 26–30). A description of a plant for the heat-treatment of Cr–V steel tools installed in Belgium in 1948 is given. The process is entirely automatic and details of the various stages are presented.—B. G. B.

Electrode Salt Baths: Production and Toolroom Models. (*Iron Steel*, 1952, **25**, Sept., 413–415). The advantages to be gained by the use of electrode salt baths for the heat-treatment of steel are outlined, and detailed descriptions are given of two types of salt bath made by Wild-Barfield Electric Furnaces Ltd. One type is designed for production work on a large scale and the other for intermittent use in toolrooms.—G. F.

How to Case Harden Steel by Nitriding. J. L. Everhart. (*Mat. Methods*, 1952, **35**, May, 90–93). The ammonia dissociation and cyanide salt bath methods of nitriding are briefly outlined. Nominal compositions of several Nitralloy grades of steel are listed, and the properties of both core and case are discussed. (10 references).—P. M. C.

The Theory and Practice of Nitriding. (*Chem. Age*, 1952, **67**, Sept. 6, 329–331). The history of nitriding is outlined, with references to the literature. Recent advances are quoted, and the advantages of the process are discussed.—T. E. D.

Induction Hardening of Gear Teeth—New Equipment Demonstrated by Birlec, Ltd., at The International Machine Tool Exhibition. (*Machinery*, 1952, **81**, Nov. 14, 1038–1040). The equipment described is designed to harden, by induction heating, only the flanks of gear teeth.—E. C. S.

A Furnace for Stabilizing Cast Iron. G. Ulmer. (*Fonderie*, 1952, July, 2999–3006). A gas-fired furnace (3·25 m. long × 2 m. wide × 1·25 m. high) for stress-relieving iron castings is described. Time–temperature curves for different positions in the furnace are presented and discussed.—R. A. R.

Continuous Annealing with Carbon Restoration. J. D. Armour. (*Indust. Heating*, 1952, **19**, Sept., 1586–1598, 1726–1729). Carbon restoration eliminates the deleterious effects of a decarburized surface layer. The furnace described was developed for the practical application of carbon restoration during annealing. It is a continuous roller-hearth furnace in which close control of the atmosphere is maintained. This atmosphere is in equilibrium with the carbon content of the core of the steel objects, and they are in the furnace long enough for the carbon in the gas phase to diffuse into the decarburized zones. This carbon balance can be maintained over the entire range of annealing and hardening temperatures. Details of the handling equipment, variety of furnace cycles, and the atmosphere control are given.—B. G. B.

Modern Method of Annealing Steel Sheets. (*Indust. Gas*, 1952, **15**, July, 312–315). Details are given of the newly installed sheet steel batch annealing furnaces at Neath Steel Sheet and Galvanizing Works. The plant comprises four lift-off type furnaces, each with three bases, all fired by town gas. The average load per base is 60 tons of sheets.—R. A. R.

Surface Hardening. O. Fischer. (*Metalloberfläche*, 1951, **5**, Aug., A120–A125; Sept., A133–A139). Methods of surface hardening are surveyed in two groups: Hardening with alteration of chemical composition, *e.g.*, carburizing and nitriding; and hardening without changing the composition, *e.g.*, flame-hardening, induction, hot-bath, and "non-cementation" hardening. The applications of the different methods are briefly indicated.—L. H.

FORGING, STAMPING, DRAWING, AND PRESSING

Model Forging Experiments: The Use of Plasticine. F. Mortimer. (*Iron Steel*, 1952, **25**, Oct., 433–436). The use of plasticine as a research tool in the study of forging problems is reviewed, particular attention being given to the work of Mowat and of Green and Cook. Results are discussed, and flow patterns are compared with those of steel specimens. The results are shown to warrant the extended use of plasticine in this field.—G. F.

Drop Forging with the Counter-Blow Hammer. R. Preuss. (*Metall*, 1952, **6**, Dec., 770–771). The advantages of the counter-blow hammers over conventional drop hammers with stationary anvil are demonstrated by reference to time studies.—J. G. W.

Comparison of Precision Die-Forging and Casting Methods. I. F. Golownew and M. A. Golownewa. (*Technik*, 1952, **7**, June, 325–326) The two processes are compared from the point of view of shapes produced, accuracy, surface finish, depth of decarburized layer, mechanical properties, and profit.—J. G. W.

Material Handling in Large and Medium Forges. Mechanical Manipulators. M. Puebla Camino, A. Urioste Haya, and P. Alvarez de Tejera. (*Inst. Hierro Acero*, 1952, **5**, July–Sept., 891–896). [In Spanish]. The use of manipulators in increasing output in forging plants without increasing the number of presses and hammers is discussed.—R. S.

Stripping Tool Design: Satisfactory Flash Removal. E. W. Mace. (*Iron Steel*, 1952, **25**, Oct., 439–440). The author discusses the correct design of stripping tools used for removing the flash from metal forgings. The punch and die comprising the tools are considered separately.—G. F.

Britain's Latest Wheel Forge. (*Brit. Steelmaker*, 1952, **18**, Dec., 680–691). **A Railway Wheel Making Plant.** (*Engineer*, 1952, **194**, Dec. 5, 753–756). **Forge for Continuous Production of Solid Railway Wheels and Disc Centres.** (*Engineering*, 1952, **174**, Dec. 5, 713–716; Dec. 12, 752–754). **Rolling Stock Wheel Manufacture.** (*Railway Gaz.*, 1952, **97**, Dec. 5, 628–633). **New British Wheel Forge.** (*Iron Coal Trades Rev.*, 1952, **165**, Dec. 5, 1245–1251). **Large-Scale Production of Wagon Wheels.** (*Brit. Eng.*, 1953, **35**, Feb., 268–274). The new plant of Taylor Bros. and Co., Ltd., Manchester, is described; its capacity is 60 wheels/hr. in sizes from 24 to 50 in. in dia.

Thicker Boiler Plate Formed Faster. (*Steel*, 1952, **131**, Aug. 11, 84–86). **New Press Pierces, Bends Boiler Parts.** (*Iron Age*, 1952, **170**, July 31, 96–97). **Hydraulic Press and Drawbench.** (*Mech. Eng.*, 1952, **74**, Oct., 818–820). **B & W's Giant Press Forms Heavy Plate, Pierces Ingots for Hollow Forgings.** (*J. Met.*, 1952, **4**, Sept., 922–923). **A Hydraulic Press and Drawbench Installation in America.** (*Engineer*, 1953, **195**, Jan. 23, 147–149). A description is given of the 6500-ton hydraulic press built and installed at the Barberton (Ohio) plant of Babcock and Wilcox Co. The press can handle sections up to 42 ft. long, 12 ft. wide, and 7 in. thick for forming into boiler drum sections, and is also used to pierce hot ingots for producing hollow forgings. An intensifier is to be added to increase the normal operating capacity of the vertical press to 8500 tons.—G. F.

Metal Working Machines. G. Oehler. (*Z.V.d.I.*, 1952, **94**, Nov. 21, 1075–1088). The presses, cold-heading machines, drop stamps, and coining presses at the 1952 Hanover Fair are described, and the most recent developments are discussed.

Protection of Mechanical Presses. J. Mossiat. (*P.A.C.T.*, 1952, **6**, Aug. 1, 261–262). The protection of the operator because of the design of the press or the nature of the work, by an external non-automatic device, or automatically is discussed. The methods of operation of some safety devices are outlined.—T. E. D.

Modern Methods of Material Handling in the Press Shop. J. E. Fox. (*Mech. Handling*, 1952, **39**, Dec., 583–587). Details are given of the methods of material handling used in the replanned press-shop of the Witton Engineering Works of The General Electric Co., Ltd.—D. H.

Production of Sheet Metal Parts by a Combination of Spinning and Stamping Operations. H. W. Snook. (*Machinery*, 1952, **81**, Dec. 26, 1313–1316). In a process developed by the Douglas Aircraft Co., in California, small sheet metal fittings are made by first spinning the blank and then completing deformation by pressing. Fewer drop hammer dies are required, and many parts which previously were made up of several pieces welded together are made in one piece.—R. A. R.

Determination of the Cross Section and Reduction in Cross Section When Drawing Semi-Finished Bars. O. Tiedemann. (*Metallwirtschaft*, 1944, **23**, July 20, 241–245). Equations are derived by which the reduction in cross section during the drawing operation can be controlled and the work involved in drawing reduced. The equations can be used to calculate the order of drawing for both constant reduction and steadily decreasing reduction. With the latter, the reductions can be arranged in a geometric or arithmetic progression, whereby the reduction at the first and/or the last die can be prescribed.

The Cupping Test as a Means for Determining the Deep Drawing Properties of Sheet and Strip. H. Beisswänger. (*Metall*, 1952, **6**, Dec., 744–753: *Iron Steel Inst., Translation Series*, 1953, No. 466). The author demonstrates by his own and other investigations that the AEG cupping test is a satisfactory measure of deep-drawing capacity, whereas the Erichsen and tensile tests are not. He found that, for sheets ranging in thickness from 0·5 to 2·0 mm., a 32-mm. dia. punch and a 38-mm. die were suitable, and the maximum blank diameter was then almost independent of sheet thickness. Outside this range the same degree of independence could be achieved by a suitable choice of punch and die radii. The test, as described, has been submitted for acceptance as a German Standard.—J. G. W.

Cup Drawing From a Flat Blank. S. Y. Chung and H. W. Swift. (*Inst. Mech. Eng., Advance Copy*, Nov. 30, 1951). The paper is divided into two sections: experimental and analytical investigations. The forces, work, and strains involved, and the conditions for successful drawing of a cylindrical shell from a flat circular blank were studied. The experiments were carried out in a 50-ton press, on 4-in. dia. × 0·025 to 0·060 in. thick blanks. Most of the work was carried out on a low-carbon rimming steel, and comparative tests were made with aluminium, brass, and copper. The conditions examined included methods of blank holding, drawing ratio, punch and die profile radii, punch-die clearance, and blank thickness. The analytical investigation deals with the stresses and strains in the region of true drawing, and considers the effects of bending, thickness changes, strain-hardening, blank-holding force, die profile friction, and tool geometry. Theoretical punch load-travel diagrams, process work, maximum punch loads and strains are compared with the experimental results. The theory can be applied with confidence in predicting punch loads and strokes, and in prescribing power and strength ratings for deep-drawing presses. (20 references.)

Deep Drawing of Hollow Bodies from Thick Steel Sheet. H. D. Feldmann and U. Bauder. (*Stahl u. Eisen*, 1952, **72**, Nov. 20, 1531–1536). Correspondence on a paper by Bauder (*see J. Iron Steel Inst.*, 1951, **169**, Nov., 296). Feldmann claims that the larger number of annealing, pickling, and phosphating stages employed in the double-drawing process proposed by Bauder makes the total work required to produce a deep drawn cup greater than that by the flow-pressing method. Bauder agrees with this but points out the other advantages of his process, which requires less heavy presses.—J. P.

High Alloy Metals Hot Extruded. (*Canad. Metals*, 1952, **15**, July, 20–21). The extrusion of alloy steel tubes at the Beaver Falls Works of Babcock and Wilcox Co. is described (*see J. Iron Steel Inst.*, 1952, **172**, Dec., 437).

Wire Drawing or Cold Extrusion? (*Wire Ind.*, 1952, **19**, Nov., 1035). The possibility of cold extrusion replacing wire drawing is discussed in the light of technical developments of both processes. It is noted that high-carbon and alloy steels are being extruded on a commercial scale.—J. G. W.

The Calculation of the Drawing Forces and the Stress Condition in Wire Drawing. T. Pöschl. (*Metallwirtschaft*, 1944, **23**, July 20, 245–249). This is a review of the earlier contributions to the mathematical treatment of wire-drawing problems. The limiting yield tensors are introduced and the basis for the derived law of hardening given. The effect of hardness values, speed of deformation, and the small, but not negligible, different increases in volume for the same deformation are briefly described.—R. J. W.

Strip and Wire Drawing: A Simple Account of Modern Theory. J. G. Wistreich. (*Iron Steel*, 1952, **25**, Sept., 391–395). The author presents a simple non-mathematical exposition of modern drawing theory. Some important features of modern plasticity theory are outlined, and the theory of drawing wide strip, developed by Hill and extended by Green, is dealt with. Essential features of the theory of drawing round wire are predicted from the strip drawing theory and from recent wire drawing and extrusion experiments.—G. F.

Winding Rope Wire, Patenting and Continuous Drawing. (*Wire Ind.*, 1952, **19**, Aug., 732–735). The production of high tensile wire for colliery winding ropes and technical developments in the drawing of wire since the beginning of the century, are reviewed.—J. G. W.

Compressed Air as Cooling Medium in Patenting Steel Wire. B. M. Pearson. (*Wire Ind.*, 1952, **19**, Nov., 1027–1028). This is a translation of a paper by W. Püngel which appeared in *Stahl u. Eisen*, 1949, **69**, Apr. 14, 262–265 (*see* J. Iron Steel Inst., 1950, **164**, Feb., 236).

ROLLING-MILL PRACTICE

The Use of Inductive Dynamometers for Measuring the Pressure of the Metal on the Roller under Industrial Conditions. A. A. Presnyakov and V. V. Bukin. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 738–741). [In Russian]. The design arrangement and performance of an inductive dynamometer used in the full-scale investigation of hot rolling is described. This type of dynamometer has the advantages of lightness, small size, ease of operation, and the possibility of obtaining remote recordings. The instruments were found to be unduly sensitive to working conditions and liable to failure. It is suggested that inductive dynamometers should be built in to the safety system of the rolling mill, the deformation being used as a measure of rolling pressure.—S. K.

The Position of the Neutral Line for Regular and Irregular Roll Profiles. H. Benad. (*Met. u. Giessereitechn.*, 1952, **2**, Feb., 48–50). The position of the neutral line is more difficult to determine for semi-symmetrical sections such as channels than for symmetrical sections such as joists, but failure to determine its position correctly shows up either in excessive wear of the mill or in the rolled product. Improved methods of locating the neutral line, based on Tafel's method, are given; the most rapid of these is a planimeter method due to Dahl.—H. R. M.

Hot Strip Rolling. (*Elect. Rev.*, 1952, **151**, Dec. 19, 1311–1318; Dec. 26, 1365–1370). This article deals with the electrical installations in the hot continuous rolling operations at the Port Talbot Works of the Steel Company of Wales. After outlining the processes, from the slab to the cold rolling mill, the electrical installations are described in detail; commencing with the slab depiler, the first part of the article describes the motors and controls of all stages up to the end of the roughing stands. In the second part, the installations in the finishing stands are dealt with.—L. E.

Principles of Continuous Gauge Control in Sheet and Strip Rolling. W. C. F. Hessenberg and R. B. Sims. (*Proc. Inst. Mech. Eng.*, 1952, **166**, 1, 75–81). Longitudinal gauge variations in hot- and cold-rolled strip are caused mainly by elastic distortions of the mill in response to variations in the roll separating force. A unique relation is shown to exist between the roll force and the thickness of the rolled strip. Two new methods of continuous automatic gauge control are described which employ an electrical roll force measuring element, the output of which continuously adjusts either the position of the rolls or the tension applied to the strip, so that a substantially constant thickness is maintained in the rolled material. Preliminary experiments on the BISRA 10 in. × 10 in. two-high mill have demonstrated that these methods are correct in principle.—P. M. C.

MACHINERY FOR IRON AND STEEL PLANT

Influence of the Properties of Plain Bearing Materials on the Performance of the Bearing. R. Kühnel. (*Metall u. Erz*, 1942, **39**, Feb., No. 3, 41–48; Feb., No. 4, 70–73). Various properties of bearing metals are studied including the chemical composition, physical properties, such as casting temperature, shrinkage, coefficient of expansion, specific gravity, structure of the metal, and mechanical properties.—L. H.

Determination of the Value of Internal Stresses in Bimetal Bearings. V. S. Rzheznikov and M. A. Babichev. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 734–737). [In Russian]. An account is given of a method for the determination of internal stresses in bimetallic circular specimens of steel inside a bearing metal. Results for steel/lead-bronze specimens are given, together with data on the effect of heat-treatment.—S. K.

Additional Dynamic Strength for Cranes. J. Götzlinger. (*Tekn. Tidskr.*, 1952, **82**, Nov. 18, 981–982). [In Swedish]. New Swedish standards have endeavoured to provide a realistic basis for designers to determine secondary stresses in cranes due to jerking or speed variations. Existing German and American regulations were considered inadequate, and tests were carried out to determine the actual stresses involved when a load is jerked at nominal hoisting speed and during travel. Formulae evolved are presented, simplified versions also being appended for hoisting stress $\psi = zv$, where z is a constant dependent on crane type and load, and v the nominal hoisting speed, and for travelling stress $\epsilon = 0{\cdot}03 + 0{\cdot}06v$ (with rail joints) and $\epsilon = 0{\cdot}03 + 0{\cdot}03v$ (without rail joints), v being maximum travel speed in m./sec.—G. G. K.

LUBRICANTS AND LUBRICATION

Significance of the Flash Point in the Evaluation of Lubricating Oils. E. Bugmann. (*Österr. Masch. Elektrowirtschaft*, 1952, **7**, June, 243–245). Although flash point is invariably included in a lubricating oil specification, its significance in practice is very doubtful. Particular cases in which it might be expected to play a part are in the lubrication of bearings, steam cylinders, compressors, and internal combustion engines, and it is argued that in all these cases its importance is overrated.—H. R. M.

Some Experiments with Sleeve Bearing Materials. B. Lunn. (*Trans. Danish Acad. Tech. Sci.*, 1952, No. 2). [In English]. The author first surveys the properties and performance of white metal and other bearing materials and then discusses a number of theories of lubrication. The construction and operation of an apparatus designed to study lubrication problems is described, and the results obtained on a variety of metal surfaces with different oils are discussed in detail. The author formulates an hypothesis concerning lubrication. (123 references).—B. G. B.

Modern Machine-Tool Lubrication Practice. W. D. Whalen. (*Mech. Eng.*, 1952, **74**, Oct., 803–809).

WELDING AND FLAME-CUTTING

Assessment of Weldability by Rapid Dilatation Tests. C. L. M. Cottrell. (*J. Iron Steel Inst.*, 1953, **174**, May, 17–24). [This issue].

Properties of Multiple-Layered Deposit Mechanical and Physical Properties of Multiple Layered 18/8 Seamless Steel in Different Directions. [In English]. I. Onishi. (*Tech. Rep. Osaka Univ.*, 1952, **2**, Mar., 101–110). [In English]. The investigation is concerned with the mechanical properties of 18/8 stainless steel welds. Crystals of the 18/8 stainless steel deposited in multiple layers are columnar, slightly inclined in the direction of welding, with growth on the 001 plane, and are not changed by depositing further layers. The tensile strength was not anisotropic, but the elongation was largest in the direction parallel to the depth of the weld.—J. G. W.

Plastic Study on Residual Stresses Due to Welding. M. Watanabe and K. Sato. (*Tech. Rep. Osaka University*, 1951, **1**, Oct., 179–190). [In English]. A theoretical evaluation of residual stresses in an infinitely large plate, caused by a single welding seam, is made, on the assumption that welding stresses arise from the constraint of plastic strains near welds caused by local heating.—J. G. W.

Failure of Rotating Shafts Due to Repairs by Welding. (British Engine Boiler and Electrical Insurance Co., Ltd., Technical Report, New Series, 1952, **1**, 114–123). *See* p. 85 [this issue].

Fabrication and Use of Steel Plate Clad with Copper or Copper Alloys. J. Valter. (*Hutnické Listy*, 1952, **7**, 8, 404–410). [In Czech]. The welding and riveting of copper-clad steel plates and its application in the construction of corrosion-resisting containers is discussed.—P. F.

Build-Up by Welding of Electric Rails. (**Weld Tests on Electro-Manganese Steel Rails**). F. Novotny. (*Schweisstechn.*, 1952, **6**, Oct., 109–114). The repair of conducting rails (0·05%–0·06% C, 2% Mn) of the Vienna railway by build-up welding is described.—U. E.

Brazing Under Protective Gas. F. Pawlek. (*Metall u. Erz*, 1941, **38**, July, No. 14, 326–329). Misconceptions and prejudices against brazed joints are first dealt with. The objections to the use of fluxes are outlined. The author then describes the brazing procedures using a protective gas, with two types of brazing metal.—L. H.

MACHINING AND MACHINABILITY

Machining—Theory and Practice. K. G. Lewis and W. Milne. (*Machinery*, 1952, **81**, Dec. 12, 1231–1236, 1247). Three important properties affecting the ability of a steel to machine other materials are: (*a*) Hot hardness; (*b*) toughness; and (*c*) wear resistance. The properties of plain carbon, low-alloy, and high-speed tool steels are considered in relation to these. The toughness and wear of medium-alloy tool steels and tungsten carbide are also considered.—E. C. S.

Evaluating Machinability of Rolled Steels, Forgings, Cast Irons. M. Field and N. Zlatin. (*Canad. Metals*, 1952, **15**, Apr. 1, 40–42). Machinability is defined as the tool life, surface finish, and power requirements obtained in metal cutting. Methods of determining machinability are discussed.—J. C. B.

Contour Grinding Requires Equipment to Suit the Job. F. C. Victory. (*Machinist*, 1952, **96**, Dec. 6, 1986–1990). The author describes equipment for shaped-wheel contour grinding operations and explains their use.—E. C. S.

Determination of Surface Quality in Turning from the Weight of the Turnings. W. Leyensetter. (*Z.V.d.I.*, 1952, **94**, Sept. 1, 825–828).

Developments in Metal Band Sawing. (*Welding and Metal Fab.*, 1952, **20**, Nov., 398–399). **Fusion Cutting: Solving the Problem of Stainless Steel.** (*Iron Steel*, 1952, **25**, Oct., 456). **Rapid Shaping and Cutting of Stainless and Alloy Steels.** (*Sheet Metal Ind.*, 1952, **29**, Dec., 1080). *See* "The 'Metalclad' Fusion Cutter," *J. Iron Steel Inst.*, 1953, **173**, Mar., 307.

Machining of Hard Metals by Electric Spark. (*Eng. Boiler*

House Rev., 1952, **67**, Oct., 285–287). **Electronics Applied to Machining Hard Metals.** (*J. Met.*, 1952, **4**, Aug., 822–824). A description is given of the Sparcatron process of machining hard metals by electric spark discharge. (*See J. Iron Steel Inst.*, 1953, **173**, Mar., 306).

CLEANING AND PICKLING

Pickling as a Preliminary Treatment to Surface Processing. R. Petri. (*Metalloberfläche*, 1952, **6**, Oct., A152–A158; Nov., A170–A174). Chemical attack by various reagents on a rolled and normalized steel sheet was measured by profile curves. To give a visible measurement of the microtoughening, the sheets were previously polished. Illustrations show the effects of sulphuric and hydrochloric acids at various strengths, temperatures and times of exposure, with and without inhibitors; the results are discussed.—L. H.

Modern Pickling Processes for Iron and Steel. E. Brauns. (*Metalloberfläche*, 1952, **6**, Oct., A145–A152). A comprehensive survey is made of methods of removing scale by pickling.

Modern Cleaning of Metals—Processes and Appliances. A. Pollack. (*Metalloberfläche*, 1952, **4**, Oct., B145–B152). A general survey is made of methods of cleaning metallic surfaces; processes are indicated, and illustrations are given of plant in present-day practice. (50 references).—L. H.

Development and Present Position of Flame Cleaning of Steel Structures with Oxy-Acetylene Flame Radiation. K. W. Sippell. (*Schweissen u. Schneiden*, 1952, **4**, Nov., 381–393). A review is given of the flame cleaning of steel structures using the oxy-acetylene process. The equipment, gas consumption, and safety measures are described. The application of flame cleaning as a preparatory method in the prevention of corrosion is discussed.—U. E.

Pressure-Jet Lapping. H. Finkelnburg. (*Metalloberfläche*, 1952, **6**, Sept., A138–A141). The principles underlying this process, developed in America and recently introduced into Germany are described. A jet, usually water, propels a finely divided lapping medium at a suitable angle on to the work. The fluid forms a film, through which the grains are propelled. They are reflected from a smooth surface, when impinging at a low angle, but strike any irregularities more or less normally, and smooth these out by shearing. A very fine polish can be obtained on a variety of articles in a very short time.—L. H.

Cleaning of Surfaces for Electroplating. J. Salauze. (*Galvano*, 1952, **21**, June, 13–21). The theory and practice of degreasing by saponification, displacement, and emulsification, and by electrolytic methods are discussed. Some typical chemicals and solutions are described.—J. P.

Metal Degreasing. J. Groome. (*Metalen*, 1952, **7**, Sept. 12, 282–285). [In English]. The author surveys and compares methods of degreasing. The advantages of trichlorethylene are described, and some points in the selection of trichlorethylene degreasing plants are considered.—R. S.

PROTECTIVE COATINGS

The Effect of Shields and Specially Shaped Anodes on Throwing Power in Electroplating Baths. J. Steiner and K. Schery. (*Metalloberfläche*, 1952, **4**, Aug., B113–B116). With the object of improving the distribution of metal on hollow cathodes, experiments were conducted on a conical cathode, using various types of shield and anode, so arranged that only the interior of the cone was coated. Different results were obtained with both conducting and non-conducting shields, in some cases with the use of an auxiliary anode. Good results were obtained with specially shaped anodes, particularly with a truncated cone, at a small distance from the surface of the anode.—L. H.

The Influence of Shields on the Cathodic Metal Distribution in Galvanic Baths. J. Steiner and K. Schery. (*Metalloberfläche*, 1951, **3**, Sept., B129–B132). Experiments are described under standardized conditions, using a ring cathode, to investigate the effect in various baths and different current densities of a shield. Circular shields, of both conducting and non-conducting materials, were placed at varying distances from the cathode, and the metal distribution measured. For each set of conditions an optimum distance was found. The effect of unsuitable bath composition or current on metal distribution was reduced by using a shield.—L. H.

Metallic Coatings by the Deposition of Vaporized Metals. R. Erdmann. (*Metalloberfläche*, 1951, **3**, Sept., B133–B135). A general survey is made of metallizing processes, including deposition by decomposition of metallic compounds, and use of the electric arc, vacua, and electric resistance heaters.

Distorted Adhesion Surfaces of the Foundation Metal: Causes, Bad Effects and Prevention. H. Reininger. (*Metalloberfläche*, 1952, **4**, Sept., B129–B137). Typical examples of non-homogeneous structures found in metals to which a metallic coating is to be applied are discussed.—L. H.

Pre-Plated Drawn Steel Wire Saves Scarce Metal. H. Kenmore. (*Mat. Methods*, 1952, **35**, May, 96–98). Steel wire heavily plated with either copper, brass or nickel and then drawn to smaller sizes is suitable for many uses where previously the non-ferrous metal was demanded. Such wire can be formed without flaking of the coating.—P. M. C.

Notes on the Current Yield in Electroplating Baths. A. Wogrinz. (*Metalloberfläche*, 1952, **4**, Nov., B161–B162).

Demonstration by Radioactive Tracers of the Adsorption of Cations by Metals. J. Palacios and A. Baptista. (*Nature*, 1952, **170**, Oct. 18, 665). In support of the hypothesis that electrode potential is due to the adsorption of cations, direct proof of the exchange of cations between electrolyte and metal is given. Such exchange occurs in small separate portions of the surface.—A. G.

Flame Plating. H. W. Perry. (*Metal Ind.*, 1952, **81**, Nov. 28, 421–422). Linde Air Products Co., New York, have developed a process for 'flame plating' metal surfaces with a film of tungsten-carbide/cobalt hard metal. Details of the process are withheld pending foreign patent applications. The plating material has a Vickers hardness of 1200 to 1500. Coatings can be varied between 0·0005 and 0·020 in., and steel, cast iron, copper, brass, bronze, magnesium, and titanium have so far been successfully plated.—P. M. C.

Flame Plating. (*Welding J.*, 1952, **31**, Oct., 945–950). The process developed by Linde Air Products Co. is described. (*See* "Flame Plating," by H. W. Perry, *Metal Ind.*, 1952, **81**, Nov. 28, 421–422).

Hardness Measurements on Electrolytic Coatings. A. Keil and O. Wüst. (*Metalloberfläche*, 1952, **6**, July, A102–A106).

Developments in Tests of Coatings for Steel Pipe. G. E. Burnett and C. B. Masin. (*J. Amer. Water Works Assoc.*, 1952, **44**, Oct., 893–911). This paper discusses some of the more recent developments in the U.S. Bureau of Reclamation tests of coatings for steel pipe. The results appear to show that for steel water pipe the linings most suitable are phenolic, vinyl, thiokol, vinyl–thiokol, and neoprene. Low temperature (− 41° F.) field exposure tests have shown that coal-tar enamel linings must be plastic to withstand cracking and flaking in cold weather.—J. C. B.

POWDER METALLURGY

Powder Metallurgy 1951. F. Benesovsky. (*Metall*, 1952, **6**, Nov., 679–685). Developments in powder metallurgy are recorded by reference to publications during 1951. (205 references).—R. A. R.

Powder Metallurgy. J. Munnix. (*Techn. Human.* 1951–1952, **49**, 3, 132–138). A descriptive survey of the preparation of powders, moulding, and sintering is given. The uses of products of powder metallurgy are outlined, and the manufacture of turbine blades, electric contacts, brake linings, and self-lubricating bushes is mentioned.—T. E. D.

Hot Pressing Powder Metals. J. F. Kuzmick. (*Machine Design*, 1952, **24**, Nov., 268–280). Hot pressing has been successfully applied where costly materials are involved and production costs are only a secondary consideration. The advantages of the method are: (1) Pressure required for hot moulding is lower than for cold pressing; (2) metal powders can be hot pressed to solid density in one operation without sintering; and (3) properties of hot-pressed alloys are similar to those of hot-forged or cold-worked annealed materials.

The Direction of Recent Developments in Powder Metallurgy. R. Kieffer and W. Hotop. (*Metallwirtschaft*, 1944, **23**, Oct. 20, 361–366). The historical development of powder metallurgy is described and followed by technical considerations of the subject. A review of the various methods of manufacture of metal powder is also given.—R. J. W.

High-Strength Sintered Iron. F. Eisenkolb. (*Metallwirtschaft*, 1944, **23**, Oct. 20, 373–377). By the use of fine-grained powder and by increasing the density by pressing, the strength of sintered iron components has been increased in recent years from 12 to 30 kg./sq. mm. Porous sintered iron can achieve these strength values using a suitable carburizing process producing a pearlitic matrix. Even higher strengths can be

obtained with extra high pressures and hot presses followed by further heat-treatment.—R. J. W.

PROPERTIES AND TESTS

The Influence of Aging on the Bauschinger Effect in Inelastic Strained Beams. T. M. Elsesser, O. M. Sidebottom, and H. T. Corten. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, Nov., 1291–1296). The investigation reported in the paper was undertaken to determine whether the full benefit of the macroscopical residual stresses could be retained by ageing the member while loaded, and so eliminate the Bauschinger effect and its detrimental influence. Tests were conducted on beams of rectangular cross-section made from annealed low and high carbon steels. An ageing treatment of 180° F. for 20 hr. was found to be sufficient to remove the Bauschinger effect in mild steel but not in the high carbon steel.—D. H.

On the Mechanism of Plastic Deformation of Metals as a Function of the Temperature and the Velocity, According to Recent Work of W. A. Wood. A. R. Weill. (*Mém. Artillerie Fran.*, 1952, **26**, No. 99, 41–57). A general survey of the experimental method using X-ray diffraction is given. A brief resumé of previous work on the resistance of metals to deformation and the theory of crystallites is presented. The mechanism of slow and rapid deformation, both cold and hot, is discussed and some results are quoted. (28 references).

The Effect of Slightly Elevated Temperature Treatment upon Microscopic and Sub-Microscopic Residual Stresses Induced by Small Inelastic Strains in Metals. H. T. Corten and T. M. Elsesser. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, Nov., 1297–1302). In load-resisting members of brass or low-carbon steel, containing favourable macroscopic residual stresses induced by inelastic deformation, the undesirable microscopic and sub-microscopic residual stresses which cause the Bauschinger effect may be removed by a slightly elevated temperature treatment, thereby retaining the full value of the favourable residual stresses.—D. H.

The Cleavage Strength of Polycrystals. N. J. Petch. (*J. Iron Steel Inst.*, 1953, **174**, May, 25–28). [This issue].

The Collapse Method of Design. (*British Constructional Steelwork Assoc., Pub. No. 5*, 1952). This 52-page publication explains the application of the plastic theory to the design of mild steel beams and rigid frames.—R. A. R.

Deformation and Fractures Produced by Intense Stress Pulses in Steel. W. M. Evans. (*Research*, 1952, **5**, Nov., 502–509). When a high explosive is detonated in contact with steel, the surface is depressed and a well-defined region of severe deformation produced. Away from this, deformation decreases, giving place to slip lines and Newmann lamellae. Characteristic fractures produced in targets of appropriate form can be related to the reflection and interaction of intense stress pulses.—K. E. J.

Cracks in Arched Tubes. S. Berg. (*BWK*, 1952, **4**, Dec., 413–415). It is shown by bend tests, hydrostatic pressure tests, and studies of fatigue and thermal stresses, that cracks occurring along the neutral axis in bent regions are due to the superposition of stresses of the same sign upon the tensile stresses which arise in the bending.—P. F.

Tear Phenomena in Bent Tubes. W. Mielentz. (*BWK*, 1952, **4**, Oct., 345–348). Fractures found in Cr–Mo–Si–V and Cr–V steel tubes along the neutral axis of bends, are ascribed to shear stresses in that region, arising from the opening up and subsequent bending back of the curvature. They have the appearance of fatigue cracks.—P. F.

Technical Report. (*British Engine, Boiler and Electrical Insurance Co., Ltd., New Series*, vol. 1, Nov., 1952). This report contains 30 case histories selected, as being of particular interest, from the many cases of material failure, damage, and accident which have come within the experience of the above insurance company. The titles of the reports of interest to the steel industry are:

Caustic Cracking in Steam Boilers. (9–56).
Bulging of a Water-Tube Boiler Drum. (57–59).
Cracking of a Boiler Shell Seam. (60–62).
Tube Failures in a Large Water-Tube Boiler. (67–72).
Corrosion of Equalising Tubes in a Water-Tube Boiler. (73–74).
Unusual Joint Failure in a Steam Pipe Range. (75–76).
Butt-Welded Joints in Pipe Ranges. (81–89).
An Unusual Turbine Shaft Failure. (102–107).
Fracture of a Steam Engine Crankshaft. (108–113).
Failure of Rotating Shafts Due to Repairs by Welding. (114–123).
Shaft Failures—Engine-Driven Generators. (124–126).
Fractured Connecting Rod Bolt. (127–129).
Brittle Fracture of a Crane Hook. (130–138).
Brittle Fracture of an Eyebolt. (139–143).
Structural Deterioration of a Steel Chain Subjected to High Temperature. (144–147).
Cracking of Bogie Wheels on a Travelling Crane. (151–153).
Fracture of a Crane Gland Iron. (154–157).
Disruption of a Hydro-Extractor. (166–171).
Multiple Cracking of Case-Hardened Pins. (178–181).
Some Sources of Error in Quasi-Static and Impact Notched-Bar Testing, by G. A. Cottell. (182–212).

Resistance to Fatigue or Endurance. R. Cazaud. (*Métaux-Corrosion–Indust.*, 1952, **27**, Oct., 386–400). The author first discusses types of stress to which parts are subjected and then considers methods of determining the endurance limit. Factors influencing the endurance limit are then reviewed.

Contribution to the Problem of Changes in Materials Due to Fatigue Stresses. A. Karius. (*Metallwirtschaft*, 1944, **23**, Dec. 20, 419–434). Earlier testing methods of fatigue stressing and their results are reviewed. The composition, texture, static, and dynamic strength properties of the experimental material is described together with the apparatus. The effect of alternate stressing by bending on the damping and elastic modulus for notched and smooth specimens is discussed in detail. (66 references).—R. J. W.

Effect of Specimen Size on the Fatigue Strength of Metals, Especially Cast Iron. O. Puchner. (*Metallwirtschaft*, 1944, **23**, Dec. 20, 434–441). Previous work on the effect of specimen size on fatigue strength for steels, light metals and cast iron is reviewed. The effect of rod diameter on the alternating bending strength, the fatigue stress concentration factor and the rotary fatigue strength of smooth, discontinuous, and cross-bored test specimens was measured. (30 references).

Fatigue Testing and the Behaviour of Materials during Alternating Stressing. II—Stepped-Amplitude Tests and Changes in Material Properties. M. Hempel. (*Z.V.d.I.*, 1952, **94**, Sept. 11, 882–887). Research into the fatigue of constructional materials is surveyed by reference to 50 publications. The following topics are discussed: fatigue testing with changing stress amplitude, endurance curves, damping capacity, effect of heat generated during alternating stressing, structural changes, and the mechanism of fatigue failure.

Dynamic Analysis of Testing-Machines with Mechanical Load Excitation. M. E. Garf. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 709–721). [In Russian]. A detailed analysis is made of the performance, and range of application of various dynamic arrangements in testing machines. For large specimens the application of a lever-crankshaft arrangement can be extended if the forces of inertia are balanced by the elastic forces of the specimen with a symmetrical loading cycle. When the specimen fails slowly, indirect load excitation, giving the most stable conditions, is recommended.—S. K.

Damping, Elasticity, and Fatigue Properties of Temperature-Resistant Materials. B. J. Lazan and L. J. Demer. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 611–648). The damping, elasticity, and fatigue properties of several heat-resistant materials were investigated in rotating cantilever-beam testing equipment. The room and elevated temperature tests were designed to reveal changes in damping energy and dynamic modulus of elasticity during fatigue tests at engineering stress levels. Fatigue curves are presented in addition to a series of new diagrams showing the effects of both stress magnitude and stress history on the damping and elastic properties. Two methods for comparing the damping energies of a group of materials are described and discussed.—B. G. B.

The Micromechanism of Rupture by Fatigue. R. Calvo Rodes. (*Inst. Hierro Acero*, 1952, **5**, July–Sept., 917–927). [In Spanish]. The author considers the alteration in the Laue spectra of an aluminium crystal due to fatigue stresses and suggests an explanation based on the theory of dislocation. The interpretation of this phenomenon of regeneration and progressive consolidation of the crystal network by alternating stresses, together with ideas expressed by the author in a previous paper, lead to an explanation of the micro-mechanism of fatigue, development of rupture, and the phenomena of incubation.—R. S.

Some Fatigue Tests on Aluminium-Alloy and Mild-Steel Sheet, With and Without Drilled Holes. C. E. Phillips and A. J. Fenner. (*Proc. Inst. Mech. Eng., Applied Mechanics*, 1951, **165**, 125–129). The authors describe fatigue tests, under pulsating direct stress, on panels approximately 0·1 in. thick and up to 12 in. wide, with and without central holes. Comparison of tests on similarly shaped panels but of different sizes, shows that larger panels are relatively weaker. The influence on the fatigue strength of varying the size of a drilled hole in a wide panel has been explored over the range of hole diameters from $\frac{1}{144}$ to $\frac{1}{3}$ of the width. Whilst in general the presence of a hole causes a marked reduction in fatigue strength, the smallest holes result in only a slight reduction.—P. M. C.

The Influence of Surface Films on Measurement of Hardness. W. Späth. (*Metalloberfläche*, 1952, **6**, Nov., A161–A163). The author surveys metal properties which influence the determination of hardness, particularly under small loads. Among points discussed are: (1) Increased coefficient of friction and tendency to weld of surfaces under compression *in vacuo*; (2) the effect of oxide films on hardness testing; and (3) the use of an oil film in measuring hardness at room temperatures.

Strain Ageing of Mild Steel: Effects of Vanadium or Chromium on the Strain Ageing of Rimming Steels. W. R. D. Jones and G. Coombes. (*J. Iron Steel Inst.*, 1953, **174**, May, 9–15). [This issue].

A General Consideration of the Phenomenon of Diffusion. L. C. Correa da Silva. (*Bol. da Assoc. Brasil. Metais*, 1952, **8**, July, 234–250). [In Portuguese]. The heat-treatment of carbon steels, ageing, and solidification are considered as examples of the importance of diffusion in metallurgy. Some mechanisms which might explain the movement of atoms in a crystal network, and the general laws governing diffusion, are described.—R. S.

Increasing the Wear Resistance of Internal Combustion Engine Cylinders. H. Wiegand and G. Schäffeler. (*Metalloberfläche*, 1952, **6**, Sept., A129–A133). The conditions necessary for maximum resistance to wear in the internal combustion engine are indicated, and improvements in pistons, rings, and cylinders from the point of view of wear resistance are described, including tinning and lead-coating of aluminium alloy pistons, hard chromium plating of pistons, and phosphating of pistons and rings.—L. H.

Tracer Technique for Studying Gear Wear. V. N. Borsoff, D. L. Cook, and J. W. Otvos. (*Nucleonics*, 1952, **10**, Oct., 67–69). An improved method of studying gear wear is described. By employing a radioactive gear in combination with a normal gear, and circulating the lubricant through a chamber monitored by a Geiger counter and scaler, a continuous indication of the total amount of metal worn from the radioactive gear can be obtained.—D. L. C. P.

Magnetic After-Effect of Cold Rolled Iron. Parts I and II. Y. Tomono. (*J. Phys. Soc. Japan*, 1952, **7**, Mar.–Apr., 174–181). [In English]. The magnetic after-effect in cold rolled iron was studied by semi-static and dynamic measurements. In contradiction to Schulze's observations, the static after-effect in a weak field and the Jordan constant were not observed. The after-effect in iron, annealed after rolling, was in accordance with Schulze's measurements. In the second part it is shown that discrepancies between measured and theoretical values of loss angles attributable to eddy currents are due principally to microscopic eddy currents.—J. G. W.

Internal Friction of Field-Cooled Ferromagnetic Substance. T. Hirone and N. Kunitomi. [In English]. (*J. Phys. Soc. Japan*, 1952, **7**, July–Aug., 364–368). [In English]. The internal friction of a ferromagnetic substance cooled in a longitudinal magnetic field was studied theoretically and experimentally. Of two theories proposed, one assumes the substance is magnetized by the displacement of the 180° domain boundary, the other that it is magnetized by the reversible and irreversible rotation of spontaneous magnetization. The latter is in better agreement with experiments on Ni_3Fe.—J. G. W.

Present State of the Manufacture of Transformer and Dynamo Sheets. W. Tofaute, H. Schlüter, and H. H. Meyer. (*Inst. Hierro Acero*, 1952, **5**, July–Sept., 875–890). [In Spanish]. After discussing the influence of composition on the electrical properties of transformer sheets in the light of their own experience, the authors consider the effect of rolling and annealing on quality. The importance of coercive force and permeability are considered and the properties of high silicon cold-rolled sheets are reviewed. The effect of the degree of cold rolling on the moment of torsion is illustrated. The magnetic permeability of 3½%-silicon cold rolled sheets is compared with that of hot rolled sheets.—R. S.

Current Sensitivity and Other Characteristics of Metal Films at Low Temperatures. A. van Itterbeek. ("*Low Temperature Physics*": *Proc. NBS Semicentennial Symposium*, Mar., 1951: *Nat. Bur. Standards Circ.* 519, 1952, Oct. 6, 243–247). Measurements of the electrical resistance of metal films at low temperatures has shown the phenomenon of a negative temperature coefficient. This has been observed with ferromagnetic films up to a thickness of 100Å.—B. G. B.

Infrared Absorption by Metals at Low Temperatures. K. G. Ramanathan. ("*Low Temperature Physics*": *Proc. NBS Semicentennial Symposium*, Mar., 1951: *Nat. Bur. Standards Circ.* 519, 1952, Oct. 6, 257–259). Quantitative measurement of the absorption of infra-red rays by some pure metals and alloys have been carried out and the results obtained are compared with those predicted by various theories.—B. G. B.

Apparatus for Measuring the Surface Tension of Cast Iron and Steel. L. L. Kunin and Iu. A. Klyachko. (*Zavodskaya Laboratoriya*, 1950, 6, 750–753). [In Russian]. The surface tension of metals and alloys can be determined at temperatures up to 1600° C. *in vacuo* or controlled atmospheres by the gas-bubble method. The specimen is contained in a crucible resting on a graphite plate and heated in a graphite resistance furnace. Gas is slowly passed through a quartz tube dipping below the surface of the metal, the pressure being observed. For cast iron containing 3·02% C, 2·25% Si, 0·66% Mn, 0·064% S, and 0·2% P the surface tensions were 1020, 1050, 1100, and 1160 dynes/cm. at 1200, 1250, 1300, and 1350° C., respectively. A simpler version of the apparatus for working with one gas only is also described.—S. K.

Non-Destructive Testing of Materials. (*International Conf. Saarbrücken*, Nov. 30–Dec. 2, 1950: Editions Métaux, St. Germain-en-Laye, 1952). This 166-page publication contains the papers at the International Conference on the Non-Destructive Testing of Materials, organized by the Institut für Metallforschung and the Institut für Schweisstechnik, at Saarbrücken, from Nov. 30 to Dec. 2, 1950. Abstracts of the papers, with the page numbers in brackets, follow:

Measurement of the Thickness of Coatings and Walls. R. Berthold. (1–6). Several methods for the measurement of thickness are described. For non-ferromagnetic materials up to 1 mm. thick, a sample is placed between a ferromagnetic support and a permanent magnet and the force of attraction is measured; the method is accurate within ± 5–10%. The thickness of a non-ferromagnetic coating (< 8 mm. thick) on a ferromagnetic base may be found by determining the inductive resistance of the system; this method is accurate within ± 2%. For measuring the thickness of ferromagnetic coatings, the energy dissipated on placing the material on an electro-magnet may be measured; this method is of use for samples up to 10 mm. thick. The determination of the thickness of thin sheet by measurement of β-ray absorption can be carried out on material up to 1 mm. thick in 0·3 sec. with an accuracy of 1–3μ. A similar method, employing X-rays, is suitable for samples between 20 and 100 mm. thick.—B. G. B.

The Continuous Measurement of the Thickness of Strip Material During Manufacture. A. T. Wuppermann. (21–24). The method described is based on the automatic comparison of the absorption of X-rays (125 kV.) by a standard material and by the sample to be examined. Variations in thickness of 0·05 mm. on 3-mm. thick steel strip can be detected. Under the least favourable conditions the precision is greater than 2%. The inertia of the measuring system is very low and measurement is not affected by the speed of rolling. The method is not suitable for steel strip less than 0·5 mm. thick.—B. G. B.

Applications of Artificial Radioactive Sources to Radiography. C. Brachet. (25–33). The use of radioactive cobalt, tantalum, and iridium for radiographic examination of materials is discussed.—B. G. B.

The Use of Radon and Radioactive Isotopes for the Non-Destructive Testing of Materials. F. Gottfeld. (35–39). Owing to the small diameter (0·5 mm.) of a normal source of radon it can be used at very short range and the exposure time is therefore short. Owing to its short half life (3·8 days) its use is restricted. The development of a number of artificial isotopes at Harwell has resulted in a number of

materials being made available which emit gamma-rays of longer wavelength, and of greater intensity than radon, with a sufficiently long half life. The use of these isotopes is discussed.—B. G. B.

Observations Concerning the Practical Use of Gamma Rays. H. Gerbeaux and M. Evrard. (41–47). The equipment and technique for use with radioactive isotopes for radiographic examination of materials is described. A number of examples showing the type of photograph obtained and its interpretation are given.—B. G. B.

On a Mechanical Non-Destructive Method of Testing Materials and Their Components. P. Le Rolland and P. Sorin. (49–55). A method of testing the rigidity of frameworks by use of the double pendulum principle discovered by Savart in 1839, is described. The mathematical principle of the instrument is explained. In practice the pendulum is suspended from the framework at a suitable point and the time of the "beats" is recorded.—B. G. B.

A New Dynamic Method for Measuring the Elastic Constants. R. Cabarat. (57–62). This method is based on the relationship between the velocity of propagation (V) of a longitudinal wave in a sample of elasticity E and density Δ, namely $V = \sqrt{E/\Delta}$. A description of the apparatus is given. The error in the determination is of the order of 0·32%. Several examples of the use of this method are cited.—B. G. B.

The Possibilities of Radiocrystallographic Analysis as a Means of Non-Destructive Testing. A. Guinier. (63–67). The application of X-ray diffraction methods for non-destructive testing is discussed. The use of the standard cards containing the crystallographic properties of substances published by the A.S.T.M. is described, together with a modification of these cards, by a system of punched holes, for automatic classification and selection.—B. G. B.

Study of Sub-Surface Defects by X-Rays. C. Legrand. (69–72). The use of the back-reflection technique in conjunction with a Geiger-Muller tube for detecting the positions of the reflected X-ray beams is described. A number of diagrams illustrating the construction and operation of the camera are given.—B. G. B.

New Possibilities for the Radiographic Determination of Stresses with Rays of Short Wavelength. H. Möller. (73–82). *See J. Iron. Steel Inst.*, 1952, **171**, July, 332.

Spectroscopy as a Method for the Non-Destructive Testing of Materials. E. Loeuille. (83–85). *See* p. 92.

Physico-Metallurgical Considerations in Ultrasonic Testing. H. J. Seeman. (87–96). *See J. Iron Steel Inst.*, 1952, **171**, Aug., 436.

The Detection of Internal Defects with the Aid of Ultrasonic Images. R. Pohlman. (97–102). *See J. Iron Steel Inst.*, 1952, **171**, Aug., 436.

Some Causes of Error in Ultrasonic Testing of Metal Parts. P. Bastien. (103–110). Four causes of error are considered. These are errors due to: (1) The physical condition and geometry of the source of emission; (2) imperfect contact between the test object and the ultrasonic source; (3) the relationship between the wavelength used and the physical structure of the material being tested (resonance effect); and (4) the nature of the material and the nature of the defects.—B. G. B.

The Belgian Method for the Ultrasonic Testing of Materials. G. A. Homes, Y. Ots, and E. Symon. (111–121). *See J. Iron Steel Inst.*, 1952, **171**, Aug., 436.

A New Apparatus for Ultrasonic Testing and Its Practical Application. J. Krautkrämer and H. Krautkrämer. (123–128). *See J. Iron Steel Inst.*, 1952, **171**, Aug., 437.

The Sweating Test. H. de Leiris. (129–135). The application of the oil–powder process for crack detection is reviewed. The use of highly coloured powders or fluorescent materials has increased the sensitivity of the method. The test is rapidly carried out with simple equipment.—B. G. B.

Magnetic and Electric Methods for the Non-Destructive Inspection of Metal Parts. W. Jellinghaus. (137–147). *See J. Iron Steel Inst.*, 1952, **171**, Aug., 437.

New Non-Destructive Electronic Methods for Testing Materials. F. Förster. (149–166). *See J. Iron Steel Inst.*, 1952, **171**, July, 332.

Ultrasonic Inspection: Its Application in the Production of Cast Rolls. E. B. Ellis. (*Iron Steel*, 1952, **25**, Oct., 429–432). The author discusses the application of the ultrasonic reflection method of detecting internal ruptures in cast rolls at Sir W. G. Armstrong Whitworth & Co. (Ironfounders) Ltd. The design and use of the apparatus, the Kelvin and Hughes Mk. IIb Crack Detector, are described and the method of interpreting the results is outlined.—G. F.

Advantages of X-Ray Inspection. J. Rigby. (*Canad. Metals*, 1952, **15**, Apr. 1, 36–37). The author indicates the uses of X-rays in the non-destructive testing of castings, pointing out that they have shown how castings may replace forgings for certain new work.—J. C. B.

The Economic Aspect of Radiographic Inspection. V. E. Pullin. (*Engineer*, 1952, **194**, Nov. 14, 641–643). The increased use of radioactivity raises questions of cost and whether the results to be expected from this method of inspection justify the expenditure. The author considers the general economics of the method but not the capital cost.—M. D. J. B.

Determination of Cracks and the Measurement of Crack Depth in Metallic Materials by Electric Voltage Measurements. A. Trost. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 308–309). The limitations and applications of the magnetic powder method and the current flowing method are discussed and compared. The basis and development of probe methods for the determination of cracks is described and examples given of the type of results to be expected.—R. J. W.

New Instruments for the Non-Destructive Testing of Magnetic Semi-Finished Bars and Parts by the Magnetic Powder Process. E. A. W. Müller. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 306–307). Advantages of the magnetic powder method for the non-destructive testing of machined and motor-car parts are first propounded and the economics of this method are considered in detail. By testing the semi-finished parts very considerable saving can be effected. Special methods for mass testing and for testing large crankshafts are described.—R. J. W.

Container for Irradiation with Radium Gamma-Rays. N. M. Varfolomeev and I. P. Belyaenko. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 754–755). [In Russian]. A convenient container for radioactive material, suitable for detection of defects under industrial conditions, is described.—S. K.

Gamma Radiology. A. R. Haworth. (*Elect. J.*, 1952, **149**, Oct. 17, 1163–1172). The author discusses the usual crack detection methods before the use of radioactive isotopes in this field, and then deals with the sources of gamma radiation, the chief of which are cobalt^{60}, tantalum^{182}, iridium^{192} and and thalium^{170}. The application to testing boiler drum seams is given with the capabilities and limitations, and the hazards to be expected.—J. C. B.

Application of Gamma-Radiation-Emitting Isotopes in Non-Destructive Testing. H. Juvan. (*Berg- hüttenmänn. Monatsh.*, 1952, **97**, Sept., 165–176).

Inspection of Castings by Gamma Rays. A. Blondel. (*Fonderie*, 1952, May, 2938–2944). The author describes the main characteristics of a radioactive source for gamma rays and the technique of examination of castings by this means. The interpretation of radiographs is discussed and safety precautions are dealt with.—R. S.

Thermionic Constants of the Iron Group of Metals. K. S. Krishnan and S. C. Jain. (*Nature*, 1952, **170**, Nov. 1, 759). Results based on the determination of saturation vapour pressure of the electron gas by an effusion method previously described are given. These fit well with Richardson's equation $i = AT_2 \exp(-\phi/kT)$ where A and ϕ are independent of temperature. Values of A and ϕ are given for chromium, γ-iron, cobalt, nickel, titanium, vanadium, and manganese.

Additional Measurements of Heat Conductivity of Nitrogen, Carbon Dioxide and Mixtures. F. G. Keyes. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, Nov., 1303–1306). Data are given on the thermal conductivity of nitrogen, carbon dioxide, and mixtures of these at various temperatures up to 350° C.—D. H.

The Influence of Aluminium and of Various Heat-Treatments on the Creep Properties of Low Carbon Steel Superheater Tubes. D. C. Herbert and E. A. Jenkinson. (*N.E. Coast Inst. of Eng. and Shipbuilders*, Oct. 24, 1952, 27–44). The creep properties of three low-carbon steels to which 1, 2, and 3 lb. per ton of aluminium respectively had been added have been determined in creep tests at 8 tons/sq. in. and 450° C. The tests were made on samples of tubes at various stages of manufacture, *i.e.*, as pilgered, and after further reduction either hot or cold. Some samples were subjected to one of various commercial annealing treatments before testing. The steel having 1 lb. of added aluminium was found to be uniformly good in creep resistance, and the steel with 3 lb. uniformly poor. A study of the microstructures did not assist in classifying the steels

according to creep resistance, but some indication was given by the McQuaid–Ehn test.—J. C. B.

High-Temperature Alloys in Relation to Gas-Turbine Design. K. L. Buckle. (*Proc. Inst. Mech. Eng.*, 1952, **166**, 1, 123–130). The phenomena of creep and fatigue assume major importance in gas turbine component design, whilst pure temperature effects, such as expansion and thermal shock, are additional problems. These properties are defined and an indication is given of their significance in the design of combustion chambers, turbine wheels, and blades. Heat-treatment considerations and fabrication characteristics are discussed in relation to material selection.—P. M. C.

The Fabrication of Chromium–Molybdenum Steel Piping for 1000–1050° F. Central Station Service. R. W. Emerson. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 869–894). The possibilities of heat-treating low-carbon Cr–Mo steels to give a wide range of mechanical properties, depending upon the type of heat-treatment specified, are discussed. Special reference is made to obtaining the optimum properties at 1000° and 1050° F. Data on the structural stability of the 2·25% Cr, 1% Mo steel are presented together with impact test data both before and after 2000 hr. at 1050° and 1150° F. The author concludes that satisfactory welds can be made in heavy wall (1·5–3·5 in.) tubing having mechanical properties equal to that of the parent metal.—B. G. B.

Creep-Rupture of Several Sheet Steels. G. V. Smith, E. J. Dulis, and E. G. Houston. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 857–868). The results of creep-rupture tests carried out on several American alloy steels in sheet form are presented. The steels used were of the Cr–Ni, Cr–Ni–Mo, and Ni–Mo types.—B. G. B.

Non-Critical Materials for High Temperature Work. (*Mech. World*, 1952, **132**, Sept., 115–116). Brief mention is made of the use of certain low-alloy steels containing chromium, molybdenum, and vanadium, and ceramics for high-temperature work. Some properties of typical materials are given.

A Time-Temperature Relationship for Rupture and Creep Stresses. F. R. Larson and J. Miller. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 765–775). A relationship previously used to evaluate the relative effects of time and temperature on the tempering of steels has been adapted to rupture and creep behaviour and applied to existing data on several alloys with success. Methods are described whereby short-time tests can be used to determine long-time properties.—D. H.

Effect of Temperature Variations on the Long-Time Rupture Strength of Steels. E. L. Robinson. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 777–781). The paper presents a method of computing the factor of safety of a structural member with reference to a stated life when operating under stress at high temperature, when the temperature varies or when the stress varies moderately according to some definite pattern.—D. H.

High-Temperature Stress-Rupture Testing of Tubular Specimens. L. F. Kooistra, R. U. Blaser, and J. T. Tucker, jun. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 783–792). A method has been developed in which a tubular specimen under internal steam pressure, and at a controlled temperature, is tested up to stress-rupture. The method closely simulates service conditions. The apparatus is described and a number of test results are discussed in relation to similar data obtained on simple tensile specimens. Failures obtained under test conditions are compared with similar failures suffered by tubes in actual service.—D. H.

Rupture and Creep Characteristics of Titanium-Stabilized Stainless Steel at 1100 and 1300° F. J. W. Freeman, G. F. Comstock, and A. E. White. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 793–801). Creep and rupture strengths have been established at 1100°, 1200°, and 1300° F. for a titanium-stabilized 18/8 stainless steel heat-treated at 1900° and 2050° F. Several titanium/carbon ratios were included as a variable. In general the data for 18/8 steels did not show as high or as low values as have been reported for 18/8 plus titanium or 18/8 plus niobium.—D. H.

Sub-Zero Technique in Engineering. R. H. Warring. (*Mech. World*, 1952, **132**, Sept., 106–107). Details are given of the application of workshop refrigeration equipment to the stabilization of precision parts and to expansion fitting. The use of refrigeration in research for components designed to work at sub-zero temperatures is mentioned.—D. H.

Low Temperature Steels: Properties and Recommendations. J. S. Bristow. (*Iron Steel*, 1952, **25**, Oct., 447–451). The author reviews the literature concerning the mechanical properties of steels at low temperatures. The tensile strength increases as the temperature decreases, whilst carbon and ferritic steels show transition from ductility to brittleness only if notched, thus producing triaxial stresses. Steels which can be safely used for triaxially stressed parts are listed.—G. F.

Properties and Testing of Some Czechoslovak Steels and Alloys at Low Temperatures. J. Dobrý. (*Hutnické Listy*, 1952, **7**, 9, 461–473). [In Czech]. Experiments and equipment for the determination of the tensile strength, ductility, and impact strength of a number of Czechoslovakian steels, including rimming basic-converter and killed open-hearth mild steels, low-alloy steels, nitriding, and heat-resisting steels, subjected to various heat-treatments are described. The temperature range of the tests was from − 20° to + 100° C. The results are presented in graphic and tabular form.—P. F.

Behaviour of Metallic Materials at Low Temperatures. M. Torrado Varela. (*Inst. Hierro Acero*, 1952, **5**, Oct., 1020–1029). [In Spanish]. The physical and chemical properties of the stratosphere are stated. The effects of anisotropy at low temperatures and the possibilities of changes in crystal form are considered. The results of trials with steels, aluminium and magnesium alloys, showing the effects of stratospheric temperatures on their mechanical properties, are studied. Compared with the terrestrial atmosphere, corrosion is less to be feared, the elastic limit and stress to rupture of many materials (notably excepting tin) increase, notch toughness increases slightly in the case of metals having face-centred cubic structure, but decreases in those metals not having this lattice. Low-carbon steels undergo the most reduction in notch toughness. The fatigue limit of structural alloys is not reduced but is substantially increased in those alloys subject to age-hardening.—R. S.

Gases in Metals. P. Bardenheuer. (*Metall*, 1952, **6**, July, 351–356). The author surveys the solubility of gases in liquid and solid metals, its mechanism, temperature dependence, deleterious effect of solubility changes, and the degasification of molten metals. Most of the paper is devoted to hydrogen.

Contribution to the Study of the Supersaturation of Iron with Cathodic Hydrogen. J. Duflot. (*Publications Scientifiques et Techniques du Ministère de l'Air*, 1952, No. 265). The effects of cathodic charging on the properties of soft iron are caused by the introduction of as much as 140 c.c. hydrogen per 100 g. metal. An electrolytic polishing method for producing a favourable surface for charging is described. Abrasive polishing after electrolytic treatment does not have any effect. Degassing at various temperatures (mainly 115° C. and 800° C.) under vacuum was studied, and a method of estimating hydrogen by fusion under tin at 1150° C. is described. The effect of reheating on lowering the capacity for cathodic charging is investigated, and the influence of grain size is mentioned. Changes in the appearance of the metal caused by cathodic hydrogen, and the influence on the mechanical properties are described. An increase from 55·6 to 68·7 Brinell hardness is noted. Elongation to rupture is lowered by as much as from 22% to 2% after 2 hours of treatment. (42 references).—T. E. D.

Investigations on the Substitution of Alloying Elements by Boron in Case-Hardening and Heat-Treating Steels. R. Scherer, K. Bungardt, and E. Kunze. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1433–1442). Experiments on the hardenability and mechanical properties of steels containing less than 0·005% of boron have been conducted to ascertain what improvements and what reduction of alloying elements are possible as a result of the boron addition. In Cr–Mn and Cr–Ni case-hardening steels, at least those used in thin section, boron additions make possible a saving of up to 0·7% of (Cr + Mn + Ni). In low-alloy heat-treating steels, boron additions can replace up to 0·5% of the chromium or manganese, or 0·15% of the molybdenum, as far as hardenability is concerned, but the mechanical properties of the low-alloy boron steels are not fully equivalent to those of the high-alloy boron-free materials. There seems to be little likelihood that boron can replace molybdenum or nickel in German steels.—J. P.

Study of the Mechanical Properties and Ease of Cold Working of Improved Basic-Bessemer Steel. R. Langers, H. Herbiet, and F. Montbrun. (*Rev. Univ. Min.*, 1952, 9th series **8**, Nov., 438–450). The results of a number of investigations to compare the mechanical and cold-working properties of steels

produced by the open-hearth process, normal basic-Bessemer process, and the basic-Bessemer process with an oxygen–water-vapour blast are described and discussed. Rolling tests showed that the open-hearth and improved basic-Bessemer steels were more easily rolled than normal basic-Bessemer steel. The value of the expression ($\%P + 10 \times \%N$) for the various samples of steels is related to the ease of rolling; the lower the value, the easier it is to roll.—B. G. B.

Steels in Aircraft Construction. H. Cornelius. (*Metallwirtschaft*, 1944, **23**, Jan. 20, 1–9). The development of constructional steels is first described. The composition and mechanical properties of such steels, including interchangeable case-hardening steels, are tabulated. Mn–Cr–V and Mn steels with increased strength and suitable welding properties are described.—R. J. W.

Mechanical Properties of Highly Tempered Alloyed Constructional Steels. H. Lüpfert and E. Gaiser. (*Metallwirtschaft*, 1944, **23**, Jan. 20, 9–14). An investigation is described in which ten steels low in scarce elements were compared with a molybdenum-bearing steel VCMo 140; the mechanical properties along and across the rolling direction being determined.—R. J. W.

High-Speed Steels Low in Scarce Elements. F. Homma. (*Metallwirtschaft*, 1944, **23**, Jan. 20, 14–21). The development of high-speed steels in Germany during the 1939–45 war is described together with the replacement of high tungsten-bearing high-speed steels by comparable steels low in scarce materials.—R. J. W.

Precision Springs. M. G. Fangemann. (*Machine Design*, 1952, **24**, Nov., 154–158). Factors requiring attention in the design of precision springs include temperature, deviation from Hooke's Law, permanent set, hysteresis, and creep. The effects of these factors on spring performance, and their control are discussed.—E. C. S.

Determination of the Elastic Properties of Spring Materials. E. I. Zhukovin. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 732–733). [In Russian]. In the method described, the elastic properties of materials to be used for springs are evaluated from the deflection of a specimen under a concentrated load. The apparatus is also suitable for tensile and compression tests on coil springs.—S. K.

Review of Stainless Steels Manufactured in Sweden. G. Lindh and H. Nathorst. (*Jernkontorets Ann.*, 1952, **136**, 10, 413–428). [In Swedish]. The authors review stainless steels manufactured by the Avesta, Bofors, Fagersta, Nyby, Sandviken, Söderfors, Uddeholm, and Wikmanshyttan companies and lists their characteristics and brand numbers. Tables give analyses of standard and non-standard ferritic, martensitic, ferritic–austenitic, and austenitic steels.—G. G. K.

Steels for Blades of Hot and Cold Shears in Sheet Rolling Mills. W. Förster. (*Met. u. Giessereitechn.*, 1952, **2**, Mar., 83–87). Examination of the requirements of hot and cold shear blades led to the selection of a forged ledeburitic steel, Le2 (1·6–2·2% C, 11–13% Cr) for the cold shears. For hot shear blades, in view of shortages of forging capacity in the Russian Zone of Germany, a heat-treated cast alloy steel of pearlitic–cementitic structure WA1 (0·37% C, 3·05% Cr, 0·20% Cu, 2·87% Ni, 0·23% V, 9·83% W) was chosen and has been used with success.—H. R. M.

Precipitation Hardening Stainless Steels Show Advantages Over Standard Grades. G. T. Bedford. (*Mat. Methods*, 1952, **35**, May, 99–104). Two steels, 17–7PH and 17–4PH, developed by the Armco Steel Corp., contain: (1) 0·07% C, 17% Cr, 7% Ni, and 1·10% Al; and (2) 0·04% C, 16·5% Cr, 3·50% Ni, and 3·50% Cu. Both can be readily cold or hot worked, or welded, and, by suitable heat-treatment, strengths can be developed equalling those of the carbon and low-alloy steels. Full details of treatment, properties (high and low temperature), effect of welding, available forms, and many applications are given.—P. M. C.

Carbon and Alloy Tool Steels: Problems of Standardization. H. Carr. (*Iron Steel*, 1952, **25**, Sept., 401–405). The author considers the possibility of standardizing tool steels and surveys some of the problems which would need to be solved. He concludes that standardization of composition, although desirable, is not sufficient and would need to be supplemented with rather more complex physical specifications.—G. F.

Material Selection Factor Significant in Bourdon Tubes. J. B. Giacobbe and A. M. Bounds. (*J. Met.*, 1952, **4**, Nov., 1147–1148). In discussing the selection of materials for Bourdon tubes, the authors have classified the various ferrous and non-ferrous alloys used into three groups according to the hardness level required. The groups consist of strain hardened, precipitation hardened, and heat-treated alloys, respectively. The characteristics, and particularly corrosion resistance, of the alloys in each group are discussed.—G. F.

Wire for Prestressed Concrete. B. M. Pearson. (*Wire Ind.*, 1952, **19**, Aug., 737–742, 761). Following an account of the history of prestressed reinforced concrete, the author discusses the technical merits of the product, the metallurgical requirements of steel used, the mechanical properties of wire and wire rope, and rope construction and anchorage. Finally, the process of prestressing is described.—J. G. W.

Types and Characteristics of Steel Wire Ropes Relative to their Industrial Application. A. E. Williams. (*Mech. World*, 1952, **132**, Nov., 204–208). The article reviews the characteristics of steel wire ropes of the present day. A brief description is given of rope making, and metallurgical and corrosion aspects of the subject are discussed.—D. H.

Ductile Iron—A New Engineering Material for Water Works Construction. C. T. Haller. (*J. Amer. Water Works Assoc.*, 1952, **44**, Oct., 912–922). The combination of good fluidity, high yield, and tensile strength, and toughness, has led to numerous commercial applications of ductile iron. Amongst those discussed are the production of pipe lighter in weight, but capable of withstanding higher pressure.—J. C. B.

Ductile Iron Combines Properties of Cast Iron, Malleable Iron, Steel. (*J. Met.*, 1952, **4**, Nov., 1143–1145). The properties of spheroidal carbon ductile iron are described and compared with those of malleable iron and grey cast iron. Ductile iron is shown to combine the process advantages of cast iron with the product advantages of steel, and, because of its high mechanical properties, it can be used in many applications.—G. F.

Mechanical and Physical Properties of Aluminium Cast Iron. J. W. Bampfylde. (*Brit. Cast Iron Res. Assoc.: J. Res. Development*, 1952, **4**, June, 340–359). The investigation was in three sections: (1) Cupola and crucible melted cast irons with aluminium contents from 0·7 to 9·5% without other addition. (2) Crucible melted cast irons containing approximately 2·7% total carbon, 1·0% Si, 7·5% Al, and 0·25 to 1·0% Cr. Special treatment was developed to overcome the tendency of the alloys to oxidize. (3) Cast irons (melted in a rocking arc furnace) containing approx. 3% total carbon, 1% Si, 5% Al, chromium contents from 1 to 30%. The effect of variation in the total carbon content of an iron containing 20% chromium was also studied. The results of mechanical and physical tests and details of the microstructures are given.—B. G. B.

Colours and Numbers to Distinguish Steels—Colour Code for Iron and Steel. J. Krämer. (*Met. u. Giessereitechn.*, 1952, **2**, Feb., 50–51). A three-colour code for identifying steels is described, which, using nine different colours, can be integrated with a 3-digit numerical code.—H. R. M.

METALLOGRAPHY

Microstructures of Metals. M. Field, N. Zlatin, and J. F. Kahles. (*Machinist*, 1952, **96**, Dec. 6, 1977–1982). The microstructure of a metal has a close relationship to its machinability. The authors explain the microstructure of steel and cast iron in a manner intended to guide the tool engineer.—E. C. S.

Electron Diffraction in Metal Examination. A. E. Williams. (*Min. Mag.*, 1952, **87**, Oct., 209–214). The principles of electron diffraction are described, particularly applying to examination of metals. Accuracy depends on stability of accelerating voltage and calibration by standard reference specimens. A full description is given of the electron diffraction camera made by W. Edwards and Co. (London) Ltd., based on work of Prof. G. I. Finch.—K. E. J.

X-Ray Microscopic Examination of the Walls of Steel Gas Cylinders. G. Becherer and H. Hülle. (*Met. u. Giessereitechn.*, 1952, **2**, Feb., 53–59). A general investigation into the causes of explosions in gas cylinders led the authors to expect that diffusion into the metal was leading to changes in the primary structure. To test this, thin ground sections from the inner and outer sides of the cylinder walls were compared by X-ray photography, and the necessary technique is described. No significant differences were found.—H. R. M.

Statistical Evaluation of Microstructural Indices for Piston Rings. P. A. Heller and K. Daeves. (*Giesserei*, 1952, **39**,

Nov. 13, 601–603). Controlling the quality of production of cast-iron piston rings by the pattern of the graphite formation by examining micrographs is described.—R. A. R.

X-Ray Camera for the Precise Determination of Crystal Lattice Constants at High Temperatures. E. Z. Kaminskii and T. I. Stelletskaya. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 691–693). [In Russian]. The design of a vacuum camera for the measurement of the constant for α-iron at high temperatures is described.—S. K.

Apparatus for X-Ray Structural Analysis. I. E. Dudavskii and F. I. Chuprinin. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 675–680). [In Russian]. The construction and use of an improved X-ray tube are described for which the following advantages are claimed: Ease of operation and maintenance, nearness of windows to source of radiation, sharp and adjustable focus of beam, provision of simple devices for altering the direction of the electron beam.—S. K.

Method for the Chemical Separation of Iron Niobide from Austenitic Steel. A. M. Dymov and S. S. Gorelik. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 648–650). [In Russian]. Aqueous (10%) cupric chloride solution was found to dissolve niobium carbide and austenite but not iron niobide from Nb-containing Cr–Ni–Mo austenitic steels. A 4–5-g. sample of the steel was treated with the solution for about three days, with free access of air and frequent agitation. The niobide, together with cuprous salts, is separated from the undissolved steel in suspension, and the copper salts are dissolved with ammonia. The metallic hydroxides produced are dissolved with HCl, leaving the dark precipitate of the niobide. The precipitate is washed by decanting and dried with alcohol.—S. K.

A Simple Goniometric Method for Examining Preferred Orientation in Etched Metal Polycrystals. P. Dunsmuir. (*Brit. J. Appl. Phys.*, 1953, **4**, Jan., 27–29).

Recent Advances in the Industrial Use of the Microscope. E. W. Taylor. (*Trans. Soc. Instrument Tech.*, 1952, **4**, June, 78–96). The author describes the features and applications of various modern microscopes, under the headings of: the phase-contrast, interference, fluorescence, ultra-violet, polarizing, metallurgical, microhardness testing, stereoscopic, measuring, electron and camera microscopes, a microprojector, and a microscope for measuring in three dimensions ionization tracks in photographic emulsion.—L. H.

Microstructure Investigations of Iron Ores. H. Kirchberg. (*Metall u. Erz*, 1941, **38**, Aug., No. 16, 361–365). The advantages of coloured photomicrographs are outlined, particularly for the red colours often found in iron ore specimens. Suitable films and plates, and the use of filters, are described. The author next deals with a new etching medium for the examination of ankeritic spathic iron ores. The finely ground, but unpolished specimens, etched for 2 min. in 10% aqueous hydrochloric acid, are rinsed and dried. They are then treated for 1 min. with ammonium sulphide. This colours the ankerite grey to black, leaving the spathic ironstone and gangue unattacked. Finally, the applications and technique of X-ray work are described.—L. H.

Illuminating Attachment for a Microscope. M. N. Yakovleva. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 764). [In Russian]. An account is given of a simple device to provide a source of reflected light in the immersion method of mineral investigation.—S. K.

Method of Using the 'Field Electron Microscope' and Its Scope for Application in Metallurgy. M. Drechsler and E. W. Müller. (*Metall*, 1952, **6**, July, 341–345). The principle of operation of this lens-free electron microscope is explained, and its application to the examination of surface layers, and surface reactions, including adsorption, is indicated.—J. G. W.

Some Transformations in Metallography Over the Years. G. Masing. (*Metall u. Erz*, 1940, **37**, May, No. 10, 189–192). In the study of intermetallic compounds the use of cooling curves was not sufficiently accurate. Instead of temperature arrests, other physical properties such as electrical conductivity and magnetic susceptibility were measured at different temperatures. From these, and X-ray investigations, the concept of intermetallic compounds in simple proportions had to be abandoned. The author then refers to the need for very accurate measurements of small temperature changes —as in recrystallization. He describes a suitable apparatus for this purpose, and gives an example of its use.—L. H.

The Non-Destructive X-ray Determination of Grain Size. M. von Schwarz, F. Regler, and F. Lihl. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 281–284). The application of the Laue technique for taking X-ray photographs of single crystals, mosaic crystals, and plastically deformed single crystals is described. The method, apparatus, and initial treatment of the specimen for the non-destructive investigation of texture by Regler's back-reflection method is also described. The X-ray results indicate that an apparent single crystal as shown by macro-etching may in fact have a mosaic structure.

The Application of Technical X-Ray Apparatus in a Modern X-Ray Laboratory for Investigating Materials. K. Winkler. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 287–291). This is an essentially non-technical paper in which the physical arrangement of an ideal X-ray laboratory (including the arrangement of the X-ray tubes, high-tension sources, exposure room, darkroom) is proposed.—R. J. W.

The Question of Differences in Film Density in the Operation of Coarse-Structure X-Ray Apparatus on Different Mains. H. Verse. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 291–294). In X-ray technology, even with identical exposure times and identical conditions of development of the films, variations in the amount of blackening of the films occur. The causes of these variations were investigated. The variations in the mains voltage was the most important factor.—R. J. W.

Relationships Between Changes of Tube Voltage with Time and the Intensity in Commercial X-Ray Operation. H. Verse. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 294–300). A comparison is made between the X-ray tube voltage variations with time and the equivalent steady voltage for the same effective film blackening during an exposure. The alternating voltage X-ray tubes and the Villard-type tubes are compared.—R. J. W.

The Causes of the Line Multiplication in Coarse Crystalline Material and Their Elimination by a Focusing Process with Simultaneous Movement of the Film Casette and the Material. A. Kochanovska. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 301–304). The causes of multiple X-ray diffraction rings obtained by the back reflection method when using large grained material are discussed. Experiments with large grained mild steel with low carbon content and large grained silicon, with different wavelengths ($CoK\alpha_1$ and $CrK\alpha_1$), are described. This effect can be overcome by the Seemann–Bohlin focusing method, in which the film cassette is rotated and the specimen moved during the exposure.—R. J. W.

Three-Dimensional X-Ray Studies. Egerer, Hanisch, Hildebrandt, and Kratzenstein. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 304–306). The development of the 3-dimensional X-ray technique is traced and the principles of the methods described. The two methods for the production of 3-dimensional X-ray pictures on a fluorescent screen using (*a*) mirrors and (*b*) a shutter system, are described.—R. J. W.

The Action of Oxygen on Iron–Nickel and Copper–Nickel Melts. C. von Bohlen und Halbach and W. Leitgebel. (*Metall u. Erz*, 1941, **38**, Mar., No. 6, 117–123). The authors point out that two metals may be effectively separated, if there is a marked difference in their affinities for sulphur or oxygen. Experiments are described in which oxygen is blown on to melts of nickel and iron, of varying compositions and at different temperatures. The greater affinity of oxygen for iron causes a loss of iron as iron oxide, a process which is retarded at higher temperatures. The reaction $NiO + Fe \rightarrow FeO + Ni$ is discussed in the light of the experiments.

An Aid for Making Stereographic Plots When Working With Cubic Crystals. C. Goldberg. (*Trans. Amer. Inst. Min. Met. Eng.: J. Met.*, 1952, **4**, Nov., 1160–1161). The author presents tables which make it possible to plot any plane (HKL) of a cubic crystal on a standard (001) projection if the absolute value of the individual H, K, and L is 9 or less. A standard projection can thus be made of exactly the proper size for the available stereographic net, and planes not appearing on previously published standard projections can easily be plotted. The tables will be especially useful in the study of optical reflections from etched surfaces.—G. F.

Continuous-Cooling Transformation Diagrams of Steels. W. Steven and G. Mayer. (*J. Iron Steel Inst.*, 1953, **174**, May, 33–45). [This issue].

An Aspect of Ac_1 Transformation of Steel and Austeno-Martensite Structure Formed by Rapid Heating and Cooling Process. M. Okada. (*Tech. Rep. Osaka Univ.*, 1951, **1**, Oct., 251–259). [In English]. The author explains his ideas on the transformation of steel, which are based on the phase rule and the rate of carbon migration. He applies this to explain the appearance of a layer-like mixture of austenite

and martensite, when carbon steels are heated for a short time above the A_1 point and then rapidly cooled.—J. G. W.

The Crystallographic Relationship between the Phases γ and ϵ in the System Iron–Manganese. J. G. Parr. (*Acta Crystallographica*, 1952, **5**, Nov., 842–843). [In English]. An oscillation photograph of a quenched needle of an iron–manganese alloy (18·5% Mn), and deductions from it, are shown to support Nishiyama's proposed mechanism (1936) that the face-centred cubic → close-packed hexagonal shear transformations are such that $(111)_\gamma$ is parallel to $(001)_\epsilon$.—R. A. R.

CORROSION

Recent Information and Experimental Research on Corrosion in Liquid Media. L. Cavallaro. (*Chim. et Ind.*, 1952, **68**, Oct., 511–521). The significance of electrochemical measurements compared with classical methods, and their interpretation on the basis of recent theories are discussed. The mechanisms of corrosion inhibitors and promotors either in acid or neutral media are surveyed, and the problems of passivity and of states of surfaces are mentioned. The kinetics of heterogeneous processes are related to the solving of practical problems in industry. (99 references).—T. E. D.

Borderline Cases of Corrosion of Rust-Resisting Steels. L. Piatti. (*Werkstoffe u. Korrosion*, 1952, **3**, Sept.–Oct., 325–328). There are borderline cases in which whether a rust-resisting steel will resist attack by a certain corrosive medium is determined by the treatment to which the steel has been exposed in fabrication. Chemical analysis alone may not suffice to decide the suitability of the material for the purpose, but X-ray studies are often helpful. These will reveal chromium impoverishment of the austenite, due to grain boundary precipitation of carbide or formation of the sigma phase, because the lattice parameter of the austenite is reduced thereby, as in an example quoted, from 3·594 to 3·581 Å.

Electrodeposited Coatings for Steel Exposed to Atmospheric Corrosion. (Draft Addendum No. 1 to German Standard Specification DIN 50960). (*Werkstoffe u. Korrosion*, 1952, **3**, Nov., 428–432). The object of this addendum to DIN 50960 is to survey existing knowledge of the resistance of electrodeposited coatings on steel to atmospheric corrosion and thus enable the user to select the coating metal and coating thickness to be used in given circumstances. Data are given for the rates of corrosion of lead, cadmium, copper, nickel, zinc or tin when exposed outdoors in rural, urban, industrial or marine atmospheres, as well as indoors. The discussion is limited to West and Middle Europe.—J. C. H.

Material Problems in Chemical Process Equipment. L. Piatti. (*Sulzer Tech. Rev.*, 1952, No. 1, 21–34). The old structural materials such as glass, porcelain, and stoneware have been replaced by pure or alloyed metals, and more recently by plastics. The author surveys the principal forms of destructive attack likely to be met by these materials and indicates their respective remedies.—J. C. B.

Corrosion Testing. F. L. LaQue. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 495–582). The author discusses in detail past and present methods of corrosion testing and the results obtained. Among these are corrosion in exposed and sheltered conditions, corrosion in natural waters, galvanic corrosion in water and in the atmosphere, salt spray tests, laboratory total immersion tests, and the boiling nitric acid test. (95 references).

Corrosion of Metallic Materials. M. Werner and W. Ruttmann. (*Z.V.d.I.*, 1952, **94**, Dec. 1, 1113–1121). In a survey of metallic corrosion the authors deal with causes and types of corrosion and protective coatings. (14 references).—R. A. R.

The 'Inverse Dependency' of Metallic Corrosion on Certain Variables. G. Schikorr. (*Metall*, 1952, **6**, July, 356–360). The author discusses cases of 'inversion' of the dependence of corrosion rate on certain variables, *e.g.*, the decrease of corrosion rate with acid concentration after a certain critical concentration is exceeded. Explanations are given. The author's aim is to show that the great complexity of corrosion phenomena can be reduced to the same few fundamentals.

On the Mechanism of Rust Formation on the Surface of Steels under Atmospheric Condition in Japan, and Its Prevention. M. Tagaya and S. Isa. (*Tech. Rep. Osaka Univ.*, 1951, **1**, Oct., 279–285). [In English]. The authors investigated rust formation on carbon steel and low chromium steel in the atmosphere, and methods of preventing it. They found that condensed dewdrops forming rust spots were the principal source of rusting of polished steel surfaces, that high carbon steel rusted more rapidly than low carbon steel, and 0·6% carbon steel tempered at 450° C. after quenching from 800° C. showed the highest rust resistance; further, soluble chloride and sulphate dust accelerates rust, whereas SiO_2, Al_2O_3, CaO particles had no effect.—J. G. W.

Cavitation in Turbines. R. Rochus. (*Techn. Human.*, 1951–1952, **49**, 4, 166–182). The complex physico-chemical and mechanical phenomenon of cavitation is defined. A general study of the problem is made and a coefficient of cavitation (σ) has been established. The use of this term is explained. Hydraulic experiments to determine σ_{initial} are outlined and some aerodynamic work is mentioned. Measures to avoid cavitation are proposed. (12 references).—T. E. D.

The Electrochemical Influence of Oxide Films and Oxygen on the Velocity of Corrosion of Metallic Surfaces, Particularly Iron. F. Tödt. (*Metalloberfläche*, 1952, **6**, Aug., A125–A126). The thickness of oxide films on iron surfaces can be determined by the measurement of the rate of corrosion in the initial stages. An initial period of about 0·001 sec. was measured by the use of a platinum cell and a cathode-ray oscilloscope. The results obtained are correlated with the thickness of the oxide films, and the highest initial rate is in agreement with the anodic corrosion of iron in concentrated acids.—L. H.

Caustic Cracking in Steam Boilers. (*British Engine Boiler and Electrical Insurance Co., Ltd., Technical Report*, New Series, 1952, **1**, 9–56). *See* p. 85 [this issue].

Corrosion of Equalising Tubes in a Water-Tube Boiler. (*British Engine Boiler and Electrical Insurance Co., Ltd., Technical Report*, New Series, 1952, **1**, 73–74). *See* p. 85 [this issue].

The Stress Corrosion of Metals. A. Beerwald. (*Metallwirtschaft*, 1944, **23**, May 20, 174–187). A brief review of the literature on stress corrosion is followed by a description of the methods used for testing such corrosion. Both intercrystalline and transcrystalline stress corrosion in steels is considered in detail.—R. J. W.

Stress Corrosion Cracking of Steel Under Sulphide Conditions. C. N. Bowers, W. J. McGuire, and A. E. Wiehe. (*Corrosion*, 1952, **10**, Oct., 333–341, 358–360). The chief cause of rapid failures of steel tubing in sour condensate wells appears to be stress corrosion cracking. Embrittlement due to exposure to hydrogen sulphide, though not a primary cause, may be an important factor. Failures can be eliminated or appreciably reduced by heat-treatment and/or change in the steel composition, but susceptibility to failure is increased by plastic deformation. Alloy steels have no pronounced advantage over plain carbon steels.—G. P. A.

Hydrogen Embrittlement Tests on Various Steels. F. A. Prange. (*Corrosion*, 1952, **10**, Oct., 355–360). Cathodic embrittlement tests were made on a number of alloys having good properties for use in deep corrosive wells. The tests suggest that the maximum hardness for use in embrittling environments should be Rockwell C20.—G. P. A.

Field Experience with Cracking of High Strength Steels in Sour Gas and Oil Wells. (*Corrosion*, 1952, **10**, Oct., 351–354, 357–360). This paper reports the initial activities of Committee T-P–1G set up in 1950 to study sulphide corrosion cracking of high-strength alloy steels in sour gas-condensate wells. Case histories submitted in reply to a committee questionnaire are cited. Current preventive measures are briefly described.—G. P. A.

Cracking of High Strength Steels in Hydrogen Sulphide Solutions. J. P. Fraser and R. S. Treseder. (*Corrosion*, 1952, **10**, Oct., 342–350, 357–360). A laboratory investigation of the cracking of high nickel and high chromium steels under environmental and stress conditions appropriate to sour gas condensate wells is described. Cracking can occur in simple aqueous H_2S solutions and is related to stress corrosion cracking. Factors studied include composition of the alloy and of the gaseous and aqueous phases, heat-treatment, temperature, type and magnitude of stress, and time of exposure. Protective coatings are effective only if there is no break or pinhole in the coating. A possible mechanism for sulphide cracking involving stress corrosion cracking and hydrogen embrittlement is suggested.—G. P. A.

Sour Oil Well Corrosion. J. A. Caldwell. (*Corrosion*, 1952, **8**, Aug., 292–294). The most efficient method of controlling corrosion in oil wells producing hydrogen sulphide is the use of inhibitors. Organic inhibitors of the adsorbed film or oil-wetting type are effective; inhibitors of the neutralizing type are unsuitable.—G. P. A.

Corrosion by Fluorine and Fluorine Compounds. R. Landau. (*Corrosion*, 1952, **8**, Aug., 283–288). Because fluorine tends to displace other elements and no other element is sufficiently reactive to displace fluorine, its compounds are chemically inert. Such common metals as nickel, Monel, copper, aluminium, magnesium, and steel are therefore suitable for equipment for handling fluorine. General characteristics of the fluorocarbons, and some specific fluorocarbon materials are described. Some safety recommendations are included.

Why Power Companies Should Promote Corrosion Control. H. H. Anderson. (Petroleum Electric Power Assoc.: *Corrosion*, 1952, **8**, Aug., 278–282). This is a general discussion of the types of corrosion problem experienced by power companies and of the desirability of unified investigation.—G. P. A.

Behaviour of Superheater Tubing Materials in Contact with Combustion Atmospheres at 1350° F. H. A. Blank, A. M. Hall, and J. H. Jackson. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 813–819). The work detailed is part of a programme undertaken to evaluate the suitability of commercially available alloys for superheater and reheater tubing at metal temperatures up to 1350° F. Ten Cr–Ni stainless steels, aluminized mild steel, and three non-ferrous alloys were exposed in a wide variety of combustion atmospheres. Fuels high in sulphur, alkalis, and vanadium were extremely corrosive, and all the alloys were attacked under severe conditions.—R. A. R.

ANALYSIS

Modern Physical Methods in Chemical Analysis. W. F. Elvidge. (*Times Rev. Ind.*, 1952, **6**, Nov., 37; Dec., 30–32). Emission spectroscopy developments in metallurgical analysis are surveyed, and X-ray diffraction is also discussed. The uses of the photoelectric absorptiometer and ultra-violet spectrophotometry in trace element and vitamin assays are outlined. Recent improvements in equipment for Raman spectroscopy are discussed and the wide use of infra-red absorption in the petroleum industry is mentioned. The development of polarography for the estimation of most common metals is described, as well as its applications in organic and biochemistry. Chromatography and the use of radioactive tracers are briefly mentioned.—T. E. D.

New Analytical Reactions of Cobalt—Application to Analysis of Steels. M. Jean. (*Anal. Chim. Acta.*, 1952, **6**, Mar., 278–292). [In French]. Various reagents of the barbituric series, which give colorations with cobalt ions, have been studied. The methods of synthesis of the nitrosobarbituric derivatives were the object of the study. Among the reagents studied, *iso*nitroso-malonyl guanidine is proposed as the reagent for cobalt, in view of the colorimetric determination of this element in ferrous metals, and especially in high-speed steels. Trilon *B* is also used in the spectrophotometric determination of cobalt in the same field.—R. A. R.

Some Problems in the Analysis of Steels by X-Ray Fluorescence. E. Gillam and H. T. Heal. (*Brit. J. App. Phy.*, 1952, **3**, Nov., 353–358). The measurement of the proportion of elements of atomic number greater than 20 in steels by X-ray fluorescence, using a Geiger-counter spectrometer, has been investigated primarily with a view to determining the suitability of the method as a rapid means of analysis during the steelmaking process, particularly for high alloy steels. From measurements on some Cr–Ni steels it appears that, when a very powerful X-ray tube is used, quick results of high accuracy are obtained only when more than about 10% of the alloying element is present.—B. G. B.

Colorimetric Methods for Determining Sulphur in Steel with Dr. B. Lange's Optical Electric Colorimeter. H. Pohl. (*Metallwirtschaft*, 1944, **23**, Sept. 20, 347–349). A rapid colorimetric method for the determination of sulphur in steel by the colour of a neutral solution of fuchsin is described. This method was only tested for the determination of up to 0·07% S and it was shown to be at least as good as the customary methods. An estimation took 5 min.—R. J. W.

A Method for the Volumetric Determination of Iron, Vanadium and Chromium when Present Together. W. Kriesel. (*Metall u. Erz*, 1942, **39**, Apr. ,No. 8, 143–144). The method described is suitable for vanadium slags, ores, vanadates, and ferrovanadium, and does not involve preliminary separation of the iron. The sample is dissolved in sulphuric acid, fumed, diluted, and any residue filtered. The residue is fused with potassium bisulphate and the extract added to the main filtrate. Hydrogen sulphide is passed into the filtrate, and any separated sulphide filtered off. The filtrate is again treated with H_2S in the absence of air, and excess removed by CO_2. Disodium phosphate is then dissolved in the filtrate, which is titrated to a permanent pink with standard potassium permanganate, back-titrating with arsenious acid. This gives the sum of the iron and vanadium. The vanadium is determined by reducing with ferrous sulphate solution, shaking with ammonium persulphate, and again titrating with potassium permanganate. Finally, the chromium is determined in the same solution by the usual persulphate oxidation.

Semi-Microchemical Determination of Chromium in the Course of the Smelting of Chromium Steel. B. P. Shlyapin and Z. P. Pevneva. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 661–663). [In Russian]. An account is given of a semi-micro permanganate method which enables chromium to be determined in steel in 7–9 min. with an accuracy of $\pm$ 0·02–0·03%. The 0·2-g. sample is dissolved in 10 ml. % nitric acid (1·13 sp. gr.) and after adding 10 ml. of hot water and 2 ml. of 2·5% permanganate solution, the liquid is boiled for 2 min. The boiling is continued after the addition of 2 ml. of HCl (1·12 sp. gr.) until all MnO_2 is dissolved. 10 ml. of cold water are added and the liquid is cooled. After adding 5 ml. of 10% trisodium phosphate and 10 ml. of 0·02*N* ferrous ammonium sulphate solutions, the excess of the latter is titrated with 0·02*N* permanganate.—S. K.

Determination of Phosphorus in Steels and Alloys Containing Titanium. E. F. Pen'kova, A. M. Dmitrieva and P. Ya. Yakovlev. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 744–745). [In Russian]. A method for the separation of titanium and phosphorus before the colorimetric determination of the latter is described, and test data are given.—S. K.

Spectroscopy as a Method for the Non-Destructive Testing of Materials. E. Loeuille. (*International Conf. on Non-Destructive Testing of Materials, Saarbrücken*, Nov. 30–Dec. 2, 1950; Editions Métaux, St.-Germain-en-Laye, 1952, 83–85). The importance of knowing accurately the chemical composition of steel alloys so that the subsequent thermal treatment may be efficient is stressed. Spectroscopic analysis can be rapidly carried out on very small amounts of material (10^{-3} g. or in special cases 10^{-8} g.) and is considered to be of great assistance for the testing of materials.—B. G. B.

New Colour Reaction for the Magnesium Ion. M. A. Shashkin. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 748). [In Russian]. Eikonogen is said to produce a green precipitate with magnesium in an ammoniacal solution, enabling the element to be detected in concentrations down to 1 in 40,000.—S. K.

Amperometric Determination of Manganese, Chromium and Vanadium in Alloy Steels and Cast Irons. G. A. Butenko and G. E. Bekleshova. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 650–658). [In Russian]. A simple, rapid, and fairly accurate method for the simultaneous determination of manganese, chromium, and vanadium in steels or cast iron is described. The method gave satisfactory results with steels containing 0·91–12·55% Cr, 0·24–2·26% V, and 0·15–0·46% Mn, together with 0·15–0·37% Ni, 2·74–17·23% W, and 0·20–0·36% Cu in some cases. Determinations were also successfully made for a ferrovanadium with 1·98% Cr, 38·41% V, 0·81% Mn, and 0·14% Cu, and for cast irons with 0·30–0·66% Cr, 0–0·41% V, 0–0·85% Mn, and up to 0·1, 0·12, and 0·4% Ni, Cu, and Ti, respectively. A rotating platinum electrode was used.—S. K.

Determination of Magnesium in Cast Irons. E. E. Cheburkova. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 663–666). [In Russian]. Two methods are described for the determination of magnesium in cast iron of the following composition: 3·00% C, 2·50% Si, 0·5% Mn, and 0·5–1·00% Cu. After the removal of SiO_2 and graphite from the solution of a 3-g. sample, iron is partially removed by extraction with ether and finally, together with manganese, by precipitation.—S. K.

The Determination of Some Residual Elements which Produce Harmful Effects in Magnesium-Treated Nodular Cast Iron. W. Westwood and R. Presser. (*Brit. Cast Iron Res. Assoc. J. Res. Development*, 1952, **4**, Aug., 369–386). Some pig irons are unsuitable for the production of magnesium-treated nodular cast irons because of the presence of traces of certain elements. Chemical methods for the determination of these elements (Al, Sb, As, Bi, Pb, Sn, Ti) are described.

Gravimetric Determination of Sulphur in Basic Steelmaking Slags. Methods of Analysis Committee. (*J. Iron Steel Inst.*, 1953, **174**, May, 28–30). [This issue].

Rapid Method for the Decomposition of Silicates. Iu. I. Usatenko and P. A. Bulakhova. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 745–746). [In Russian]. In the method described, silicates in materials such as coke ash, refractories and slags, are prepared for solution by fusion with anhydrous sodium carbonate in 2–3 min. at 1000° C.—S. K.

A Microreaction for the Manganese in Minerals and Silicates. A. de Sousa. (*Analy. Chim. Acta*, 1952, **7**, Nov., 393–395). [In French]. A rapid and sensitive method for the detection of manganese in ores, minerals, and silicates is described. The reagent is a 5% alcoholic solution of 8-hydroxyquinoline. A drop of the solution to be examined suffices for the test. The method can be used for field tests.—R. A. R.

Critical Consideration of the Determination of the Total Sulphur in Fuels by the Eschka Process and Proposal for a Catalytically Accelerated Treatment for Routine Investigations. W. Mantel and W. Schreiber. (*Glückauf*, 1942, **78**, Apr. 4, 185–190; Apr. 18, 220–223). The aim of this investigation was to shorten the ashing time of 3 hr. necessary for the Eschka process, by the addition of catalysts or changing the experimental conditions. The accelerating effects of various metal oxides reduced the time to 50 min. Ashing experiments, carried out in a special furnace, yielded results on the effect of temperature, of a current of cool air, of the addition of H_2O_2, and of the state of fineness of the fuel.—R. J. W.

The Determination of Sulphur in Liquids and Gases—Possible Applications of the Muffle Method. W. Lange. (*Glückauf*, 1942, **78**, Oct. 31, 650–656). A new form of the muffle method for the rapid oxidizing determination of the total sulphur in gases, liquids, and organic materials is described. Methods of this kind are, in general, limited by the analysis of the ash-free material. The influence of metals, chlorine, and nitrogen are each considered in detail.

HISTORICAL

To Explore New Ways. E. C. Bain. (*Charles M. Schwab Memorial Lecture: Yearbook Amer. Iron Steel Inst.*, 1952, 119–160). The author surveys the improving technology of iron and steel manufacture from prehistoric times to the present day, and reviews the present status of science in the steel industry. Particular reference is made to the possibilities that lie in the field of research, both competitive and co-operative.—G. F.

Two Documents on the Introduction into France of English Methods in the 18th Century. (*Techn. Civil*, 1952, **11**, 63–68). A brief account of an early French cannon foundry using English methods is given, with details of an estimate for a cannon boring plant with mention of the rate of production and fuel consumption.—T. E. D.

Cast Iron in China. A. G. Haudricourt. (*Techn. Civil.*, 1952, **11**, 2, 37–41). This is an historical note on the early development of iron-making in China and the spread of the techniques to Europe.—T. E. D.

A Remarkable Lump of Iron from the Middle Ages. E. H. Schulz and P. Bornefeld. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1448–1449). A ' ball ' of iron found in a slag tip in the remains of the iron workings of Hohenlimburg is attributed to the period from 1100 to 1400. It had a carbon content of about 1·5% and a quenched structure, and may be regarded as a characteristic product of the time of the transition from the bloomery to the blast-furnace.—J. P.

Creators of the Steel Age—VI: Henry Clifton Sorby. R. Edwards. (*Brit. Steelmaker*, 1952, **18**, Oct., 506–514). This article describes the work of Henry Clifton Sorby and his contributions to steelmaking. His main achievements were the establishment of a technique for the microscopic examination of iron and steel sections, the development of micro-photography and of macro-etching, the indication of the steel constituent later termed ' sorbite,' and the virtual establishment of the science of micro-petrography.—G. F.

Tinplate Through the Ages. F. Evans. (*Brit. Steelmaker*, 1952, **18**, Nov., 554–558). The author traces the history of tinplate manufacture, first carried out on a large scale in Bohemia in the XIIIth century. He discusses the introduction of the techniques to this country by Andrew Yarranton in 1665 and the progressive development of the industry from that period to the present day, marked by the opening of the new Trostre Works.—G. F.

ECONOMICS AND STATISTICS

Expansion Programme in Steel Industry. (*Metal Market Review*, 1952, **5**, Aug. 15, 27–29). The expansion and modernization programme which is to be carried out by the Tata Iron and Steel Company, India, is discussed. Among the major items in the programme are the construction of a new coke-oven battery, rebuilding of B blast-furnace, remodelling of an open-hearth plant to give five 160-ton capacity basic furnaces, a new skelp and strip mill, and a new tube mill (in association with Stewarts and Lloyds Ltd.). When completed (1956–57) the productive capacity of the company is expected to be a little over 930,000 tons/year.—B. G. B.

An International Comparison of the Sizes and Horizontal Organizations within the Iron and Steel Industries. (United States, Great Britain, France, Belgium, Luxembourg, and Germany). H. Steiner. (*Stahl u. Eisen*, 1952, **72**, Nov. 6, 1452–1461). The size, development and investment programmes, and management of the leading iron and steel combines in the above states are discussed as a background to the realization of the plans and future of the European iron and coal community.—J. P.

The Development of the Electric Furnace in the Steel Industry of the Saar. (*J. Four Elect.*, 1952, **61**, Sept.–Oct., 135–136). The production of steel in electric furnaces in the Saar rose from 21,000 tons in 1929 to 69,000 tons in 1951. The work carried out at a typical plant in the region is described and details of the equipment installed are given.—B. G. B.

Conservation of Scarce Materials. (*Australian Found. Trade J.*, 1952, **3**, Aug., 11–14). The recommendations of the International Materials Conference concerning nickel, cobalt, manganese, tungsten, and molybdenum conservation, are summarized. Comments on what has been, and is being done in Australia in this connection are also given.—P. M. C.

The Present Metal Situation of Finland, and Its Development Potentialities. E. Sarcander. (*Metall u. Erz*, 1940, **37**, Nov., No. 22, 464–466). Finland has very little coal, but depends on her extensive forests for charcoal, and on abundant water supplies for hydro-electric plant. Figures are given of 1938 furnace capacity, and of the production of pig iron, open-hearth and electric steel, and ferro-alloys.—L. H.

Ore Mining and Blast Furnace Industry in Hungary. E. Dobransky. (*Metall u. Erz*, 1941, **38**, Jan., No. 1, 17–22). Tables are given showing the ore and metal production in different areas from 1935 to 1938, and the production of iron and manganese ores, and pig iron, from 1920 to 1939.—L. H.

Swedish Ore Mines and Smelting Plants. E. Sarcander. (*Metall u. Erz*, 1940, **37**, Dec., No. 23, 481–483). In 1938 Sweden ranked after America, Russia, and France in the value of her iron ore production. Most of this is exported. In spite of considerable hydro-electric resources, Sweden actually imports a large amount of metal and metal products.

Mining and Metal Industries in Slovakia. E. Dobransky. (*Metall u. Erz*, 1941, **38**, Feb., No. 3, 61–64).

The Development of Mining and Smelting in Czechoslovakia from 1937 to 1940. R. Dobransky. (*Metall u. Erz*, 1941, **38**, Dec., No. 24, 525–526). The production of iron ore in the years 1937–40 is compared in tables with that of the records available for 1920–26.—L. H.

Ore Mining in Greece. R. Dobransky. (*Metall u. Erz*, 1942, **39**, Mar., No. 6, 111–113). The production of chromium and nickel ores from 1913 to 1938 is given.—L. H.

Mining and Metal Production in Yugoslavia. R. Dobransky. (*Metall u. Erz*, 1941, **38**, July, No. 14, 330–334; Aug., No. 15, 351–352; Sept., No. 18, 411–414). The industries of Yugoslavia are described. Large quantities of iron ores, and small amounts of manganese and chrome ores were produced, most of which was exported. Export figures for 1928–39 are given.

Yugoslavia's Metal Output. (*Metall*, 1952, **6**, Dec., 791). Figures for Yugoslavian production of metalliferous ores, pig iron, steel, and non-ferrous metals for the years 1939, 1950, 1951, and first half of 1952 are given.—J. G. W.

Turkish Mining Industry, in the Light of New Problems. H. Baum. (*Metall u. Erz*, 1941, **38**, Aug., No. 16, 372–374). The effect of the outbreak of war on the Turkish economy is discussed, followed by a description of the metallurgical industries. Production of iron, manganese, and chromium ores all increased greatly in the three years preceding the war. The production in 1939 was—iron ore, 143,000 tons; manganese ore, 3339 tons; chromium ore, 191,644 tons.—L. H.

The Metal Economy of the Soviet Union. (*Metall u. Erz*, 1941, **38**, Dec., No. 23, 505–510). The production of manganese ore in the Soviet Union from 1932 to 1938 is given in tables, together with the amounts imported by Germany.—L. H.

Manchukuo—a Developing Industrial State. H. Baum. (*Metall u. Erz*, 1941, **38**, Mar., No. 5, 110–113). The iron ore deposits of Manchukuo are amongst the most abundant in the world; also there is a plentiful supply of coal. The modern Manchurian iron industry began in the 1914–18 war. In 1936 the production of pig iron was about 650,000 tons. Since 1935 a growing tonnage of steel ingots has also been produced. The location and potentialities of Manchurian industrial concerns are indicated.—L. H.

MISCELLANEOUS

The Steel Industry and the Railways. A. G. Thomson. (*Brit. Steelmaker*, 1952, **18**, Oct., 502–504). The author discusses the close co-operation existing between the steel industry and British Railways, and shows how their interdependence is of inestimable value to rearmament and the export drive in alleviating difficulties arising from shortages of materials and manufactured goods.—G. F.

Open Day at Fulmer Research Institute. (*Metallurgia*, 1952, **46**, Oct., 195–198; *Sheet Metal Ind.*, 1952, **29**, Nov., 1006–1007). The first five years' work on sponsored research at the above Institute is reviewed.—B. G. B.

The Inauguration of the I.R.S.I.D. Laboratories at St. Germain-en-Laye. H. Malcor. (*Usine Nouvelle*, 1952, Oct. 30, 6–7). An account is given of the inauguration of the new laboratories and of the address by H. Malcor (President of IRSID), in which he outlines the importance of iron and steel research and the part played by IRSID.—T. E. D.

BOOK NOTICES

ANGLO-AMERICAN COUNCIL ON PRODUCTIVITY. "*Metalworking Machine Tools.*" La. 8vo, pp. xi + 88. London, 1953: British Productivity Council. (Price 3*s.* 6*d.*)

This report describes the findings of a team which studied the American metalworking machine tool industry in 1951. It is concerned chiefly with production matters, *e.g.*, workshop methods, supervision, material control, labour relations and incentives, trends in design and so on, and will, therefore, be of greatest interest to machine-tool manufacturers themselves, and to others concerned with machining. There is little that is novel in the materials employed, except, perhaps, the successful use of plastic plates against the slideways of planing machines, etc., to avoid heat transference and warping of the table; such materials are also used for lead-screw nuts. Flame- and induction-hardening are often used on bed and saddle surfaces, either directly or through the medium of hardened strips bolted on. The most interesting future for the industry seems to lie in wholesale re-design of machines on 'unit' lines, that is, the construction of simpler standard units from which a variety of appliances having all the range of motion of existing specialized machines may be assembled.—J. P. S.

BILLIGMANN, J. "*Stauchen und Pressen.*" Handbuch für die bildsame Kalt- und Warmformgebung von Stählen und Nichteisenmetallen in der Serien- und Massenfertigung. 8vo, pp. xvi + 574. Illustrated. München, 1953: Carl Hanser Verlag. (Price DM 28.50)

This is a remarkably comprehensive handbook for the production engineer who is concerned with the batch and mass production of small forgings, notably of bolts and nuts. It covers ferrous and non-ferrous materials, hot and cold processes, machine tools, ancillary treatments, and also economic aspects of production. The author, well known in Germany for his investigations of heading processes, has written what, even by the acknowledged high standards of German technological reference books, may well count as a classic. He has found the happy balance between instruction and handy reference, and between shop and laboratory data, and, in spite of the vast ground covered, he has the matter firmly in hand.

The manufacturing processes described by the author are an off-shoot of drop forging, and in older text- and handbooks are given no more than a short chapter built around upsetting in a forging machine. The cold- and hot-heading industry has, however, grown tremendously in recent years, and the processes have acquired distinctive features, so that the appearance of a book of this size and standard is most welcome. The reason for the rapid and continued expansion of the industry is clearly illustrated by the author's cost comparison of hexagonal bolts manufactured by machining, combined hot-forging and machining, and by cold-heading (Fig. 449); the cost ratio is, roughly, 8 : 3 : 1. At the same time it is notable how varied the plastic working operations are, so that 'heading' or 'upsetting' has become a most inadequate term: shearing, upsetting, extrusion, stamping and coining all enter into modern bolt manufacture. In this connection, the omission of thread rolling and of shearing, presumably because they are neither 'pressing' nor 'upsetting,' seems to the reviewer unnecessary pedantry, and might well be remedied in later editions.

It is invidious to single out individual chapters for meritorious mention, but the production engineer, no doubt, will be particularly grateful to the author for his masterly and thoroughly practical treatment of the mechanics of upsetting and drop forging, copiously documented by graphs and tables on raw-material dimensions and press loads, and for the chapter on cost comparison of alternative manufacturing methods. Information about processes and machines is thoroughly up-to-date and backed by about 350 references to Continental, British, and American technical and patent literature up to 1952.

The author has done such a good job that any criticism seems like cavil. It does, however, seem surprising that only three pages are devoted to lubrication (and coating). Perhaps this merely reflects the want of factual information and points to the need for further investigation.

J. G. WISTREICH

BRITISH ELECTRICAL DEVELOPMENT ASSOCIATION. "*Higher Industrial Productivity with Electricity.*" (Electricity and Productivity Series No. 1.) 8vo, pp. xv + 146. Illustrated. London [1953]: The Association. (Price 8*s.* 6*d.*)

This well illustrated, well produced little book is the non-technical forerunner of a series intended to show the advantages of the application of electric power, lighting, and heating in industry. Among the fairly obvious points it makes are that smooth, planned, factory layout depends on the ability to apply power where it is needed in the form of electric motors, that better and more uniform lighting leads to better work and more of it, and that electric heating is quick, clean, and readily controllable. Blast-furnace skip-hoist chargers, foundry mechanization, and induction heating are among the examples given to illustrate these points. In some cases, the Association appears to be knocking on an open door, in others there is undoubted scope for the greater use of electricity, but one of the real problems, the *better* use of electricity at a time when generator capacity is fully utilized and new equipment not yet available, is not touched upon.—J. P. S.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION. "*Physical Constants of some Commercial Steels at Elevated Temperatures.*" (Based on measurements made at the National Physical Laboratory, Teddington.) Edited by the Metallurgy (General) Division Thermal Treatment Sub-Committee of the Association. Foreword by Ezer Griffiths. La. 4to, pp. x + 38. Illustrated. London, 1953: Butterworths Scientific Publications. (Price 21*s.*)

Metallurgists have too often been forced into dealing with their subject largely in verbal or qualitative terms. However, more and more quantitative data are fortunately becoming available, and the present publication is a case in point. It provides values of numerous constants over a considerable range of temperature for a selection of typical commercial steels.

The constants are of the kind needed for heat-flow calculations. Specifically, they are: Total and specific heats, coefficients of thermal expansion, electrical resistivities, thermal conductivities, densities, and thermal diffusivities. The data have been tabulated at 50° C. intervals (with equivalent Fahrenheit scales), and, in addition, total-heat/temperature and thermal-expansion graphs are plotted.

Some of the constants have been obtained by direct measurements, others derived by calculation. The experimental work was carried out at the National Physical Laboratory and in the main has been described in Iron and Steel Institute publications. However, considerable editing into the present convenient form has been necessary.

Short summaries of the experimental techniques are given, as well as of the mathematical methods used by the editors.—A. R. BAILEY.

CAZAUD, R. "*Métallurgie.*" A l'usage des ingénieurs, maîtres de forges, directeurs et contremaîtres d'usines métallurgiques de fonderies de métaux, etc. 65e Edition. Sm. 8vo, pp. xxvi + 326 + xlviii. Illustrated. Paris, 1953: Dunod. (Price 450 fr.).

The latest edition of this 'Aide-Mémoire' differs only slightly from the previous one published in 1950 and remains a most useful handbook of metallurgical information.

Sections are included on the mechanical testing of metals, thermal and thermochemical treatments, and the metallurgy of iron and other metals, including the properties and uses of major alloys, whilst an appendix deals with the corrosion of metals and various solutions to this problem. The book is of course intended for French readers, and one could wish for a similar English work covering the same ground.—A. GRIEVE.

"*Druck-, Zug- und Mengenmessung.*" (Wärmetechnische Lehrblätter, Teil 5. Herausgegeben von der Energie- und Betriebswirtschaftsstelle des Vereins Deutscher Eisenhüttenleute (Wärmstelle Düsseldorf).) 8vo, pp. vi + 155. Illustrated. Düsseldorf, 1952: Verlag Stahleisen m.b.H. (Price DM 8.50)

This book is part of a series of publications on various aspects of heat engineering, and it places valuable information at the disposal of the plant engineer as well as those interested in questions of pressure and flow measurement. The material as arranged is equally useful as a source of reference and as an instructive course for students. The subject is dealt with in eight chapters; a ninth presents the respective German DIN Standard Specifications, including definitions, instrument specifications, and the capacity-meter test code.

The concept, definition, and physical aspects of pressure and the technical metric units used in gauging it are presented. Much attention is justifiably paid to the correct disposition of the pressure leads from the tappings to the instrument and to the location, design, and arrangement of the actual piezo tappings. The essential need for experience in order to get good results with a metering circuit for gases and liquids is shown by examples and a description of the pitfalls to be avoided.

The means of creating artificially a pressure difference to be employed in gauging flow is discussed in detail, and data are supplied for the correct design of inlet bellmouths, orifices, nozzles, and Venturi meters, whilst instruments of the tube type—Pitot, Pitot static tubes and Pitot cylinders—are only mentioned. The examples given, nearly all dimensioned, mostly follow DIN specifications, but one or two show arrangements which have not come up to requirements. The importance of designing correctly any pressure equalizing chamber in respect to cross-sectional dimensions, tapping size, and location of take-off nipples is illustrated. The special requirements in metering flow with transport of sediment, and the possible errors in orifice and nozzle indication owing to deposit of sediment are considered. Equipment and procedure for calibration for the various differential pressure ranges, and the possibilities of error involved, are described.

The largest section of the book deals with the means of registering meter indications; only the basic principles are discussed, and circuit arrangements are described. Industrially manufactured reading instruments are illustrated, including remote-reading arrangements actuated by a mercury U-tube with step resistance, featuring automatic compensation for temperature and pressure fluctuations, ring-type balances of various kinds both with and without protection circuits, float-type instruments with and without magnetic feeler, a floating-bell instrument, as well as membrane indicators with electrical and mechanical transmission. Woltmann, disc, and positive piston meters are examples given for instruments used specifically for gauging in closed conduits. For metering spouting liquid flow, a tilting-type meter is suggested, whilst mention is made of weirs and Venturi channels as a means of gauging large flow rates in open channels.

Protective sealing by means of a gas or liquid is discussed for cases where the flow to be metered is of an aggressive nature, to which filter arrangements are added if sediment is transported. Lastly, mention is made of stoichiometric and injection methods used in flow metering.

Notwithstanding the condensed form of the presentation which made selective treatment in varying degrees of detail necessary, the book is a most useful and informative contribution in this field.—A. F. WINTERNITZ.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY. "*Fatigue and Fracture of Metals.*" A Symposium held at the Massachusetts Institute of Technology, June 19–22, 1950. Edited by William A. Murray. With a Foreword by Jerome C. Hunsaker. 8vo, pp. viii + 313. Illustrated. New York, 1952: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 48*s.*)

Of the fourteen separate papers in this collection, four deal with brittle fracture, nine with various aspects of fatigue, and only one is concerned with the possible interrelation between the two topics. Moreover, although the foreword refers to panel discussions which "served to round out and consolidate opinion at the time . . . it was found inadvisable to include transcripts of these panel discussions; when once the crystallinity of face-to-face debate has gone, the cleavages and slip planes of informality are too nearly dominant in the record." Thus we are left with the bare facts and no correlation.

The only course then is to attempt ourselves to effect again the consolidation, which proved so unhappily evanescent. To this end the several papers call for prolonged study rather than casual reading, but even on first examination certain points spring to the eye. It is, for instance, gratifying to notice the chiefs of the N.A.C.A. joining with Dr. Peterson and Dr. Templin in a strong plea for better stress analysis in relation to fatigue loading, while Dr. Jonassen affords several examples of reduction of liability to brittle fracture by improved detail design. It seems that the Conference as a whole would probably have endorsed the finding that a great many of our present troubles are due to bad design cloaked by inaccurate stress analysis, and that the designer must put that right before he can expect real sympathy from the metallurgist. The Conference appears also to have accepted the two-strength theory of brittle and ductile fracture and Dr. Orowan elaborates a precise 'reason why' based on a modification of the Griffith crack theory. On the other hand, Professor Gensamer doubts whether we yet know all the facts of behaviour in respect of fracture, and considers the phenomenon as yet very ill understood. The Conference as a whole seemed to rely upon the concept of cumulative damage and perhaps to accept the view that fatigue is a race between hardening and damage. At the same time Dr. Weibull points out that fatigue is essentially a statistical effect and establishes his claim that the phenomenon must be regarded statistically. Mr. Horger demonstrates the improvement that can be achieved in bending fatigue by inducing mean compressive stresses in the regions of high stress, but is careful to point out that the stress put in may evaporate in use, and that anyway it is difficult to put the stress in without altering the material in other ways also. Professor MacGregor reports a progressive increase of transition temperature with cycles of repeated stress both above and below the limiting safe fatigue range.

Major Teed demonstrates how ill-equipped we still are to discuss what should happen in the complex non-homogeneous and anisotropic structure of even the most ordinary alloy; while Professor Norton rounds out the point by discussing the various techniques available for looking to see what does happen.

The book is well bound and beautifully printed on fine glossy paper, and it is, of course, far too dear.—H. L. COX.

"*The Wire Industry Encyclopaedic Handbook*, 1953." 8vo, pp. 448. Illustrated. London, 1953: The Wire Industry, Ltd.

Some half of this volume is taken up with a buyers' guide, and advertisements, which between them provide a panorama of wire products and their makers. The remainder provides useful technical information on, for instance, wire drawing, the care of wire ropes, etc., and concludes with a section, alphabetically arranged, defining a large number of metallurgical terms and processes met with in the industry.—J. P. S.

AMERICAN SOCIETY FOR TESTING MATERIALS. "*Symposium on Determination of Elastic Constants.*" Special Technical Publication No. 129. Presented at the Fifty-Fifth Annual Meeting (Fiftieth Anniversary Meeting) of the American Society for Testing Materials, New York, N.Y., June 25, 1952. 8vo, pp. [iv +] 100. Illustrated. Philadelphia, Pa., 1952 : The Society. (Price $2.00)

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"*The Engineer Buyers Guide* 1953." 8vo, pp. 606. London, 1953 : The Engineer. (Price 5*s.*)

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